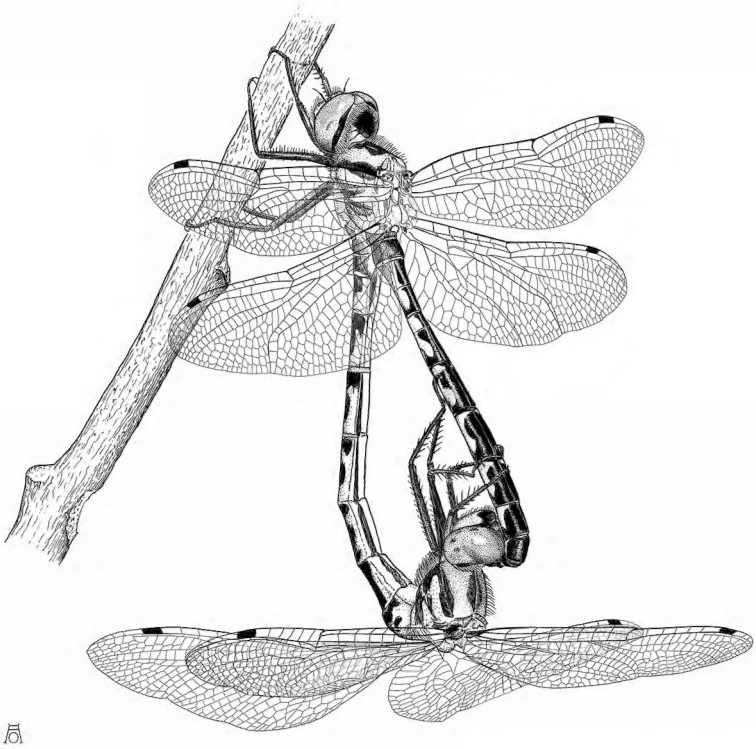
THE AUSTRALIAN Entomologist

published by
THE ENTOMOLOGICAL SOCIETY OF QUEENSLAND



Volume 45, Part 2, 30 June 2018

Price: $8.00 per part

ISSN 1320 6133

THE AUSTRALIAN
Entomologist

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OBSERVATIONS ON THE ECOLOGY OF THE SILKY HAIRSTREAK, *PSEUDALMENUS CHLORINDA* (BLANCHARD, 1848) (LEPIDOPTERA: LYCAENIDAE)

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Abstract

Acacia irrorata ssp. *irrorata* Sieber ex Spreng. and *Acacia binervata* DC. (Fabaceae) are newly recorded as larval food plants in New South Wales for *Pseudalmenus chlorinda barringtonensis* Waterhouse, 1928 and *P. chlorinda chloris* Waterhouse & Lyell, 1914, respectively. Attention is drawn to the ecology of the larval attendant ant *Anonychomyrma biconvexa* (Santschi, 1928), particularly its apparent dependence on old mature eucalypts and potential as an indicator species of old growth habitat.

Introduction

The lycaenid butterfly *Pseudalmenus chlorinda* (Blanchard, 1848) is endemic to southeastern Australia, where it occurs predominantly in cool, montane habitats, including subalpine areas above 1200 m, of the southeastern highlands and Tasmania. The life history, general biology and basic ecology of the species are well known (see Braby 2000 for review). The larvae have an obligate relationship with the dolichoderine ant *Anonychomyrma biconvexa* (Santschi, 1928) and specialise on the foliage of *Acacia* spp. (Fabaceae: Acacieae). Up to nine species of *Acacia* have been reported as larval food plants (Braby 2000) and these include taxa with bipinnate leaves only (*Acacia dealbata* Link, *A. decurrens* Willd., *A. elata* A.Cunn. ex Benth., *A. mearnsii* De Wild., *A. terminalis* (Salisb.) J.F.Macbr. and *A. trachyphloia* Tindale) and phyllodes (*A. melanoxylon* R.Br., *A. obtusifolia* A.Cunn. and *A. pravissima* F.Muell. ex Benth.). The larval food plants range from saplings (less than 1 m high) to mature trees (greater than 10 m high).

In New South Wales, the larval food plants include *A. melanoxylon, A. dealbata* (for subspecies *P. chlorinda barringtonensis* Waterhouse, 1928) (Burns 1948), *A. elata*, *A. terminalis* (for subspecies *P. chlorinda chloris* Waterhouse & Lyell, 1914) (Edwards and Edwards 1963, Binns 1976), *A. obtusifolia* and *A. trachyphloia* (for subspecies *P. chlorinda zephyrus* Waterhouse & Lyell, 1914) (Common and Waterhouse 1981). The last mentioned subspecies also frequently uses *A. dealbata* and *A. melanoxylon* in NSW (*e.g.* Tallaganda National Park near Hoskinstown and Mt Canobolas near Orange) (M.F. Braby and J.J. Armstrong, unpublished data). *Acacia melanoxylon* is also used by *P. chlorinda chloris* in NSW, at Mt Kembla near Wollongong (M.F. Braby, D.R. Britton and J.J. Armstrong, unpublished data) and at Bowral and Robertson (S.S. Brown pers. comm.). D'Abrera (1977) listed '*Acacia ovata*' as a food plant of *P. chlorinda barringtonensis* but it is not clear what species this name refers to – it might refer to *Acacia*

doratoxylon var. *ovata* Maiden & Betche, which is a synonym of *Acacia granitica* Maiden, a species which occurs within the northern range of the subspecies. Moss (2010) listed *A. irrorata* Sieber ex Spreng. as a food plant for the species in his catalogue of butterfly food plants, but provided few details; presumably the record refers to *P. chlorinda barringtonensis* from northern NSW but this was not explicitly stated and the record was not tabulated in Part C as a 'new host plant record'. Thus, the record remains unconfirmed.

The aim of this note is to document two additional larval food plant records of *P. chlorinda* from NSW. We also briefly discuss some overlooked aspects of the ecology of the species. Vouchers of the plant specimens have been deposited in the Australian National Herbarium (CANB).

Observations

Acacia irrorata ssp. *irrorata* Sieber ex Spreng. (Fabaceae)

Voucher M.F. Braby 208 (CANB)

The immature and adult stages of *P. chlorinda barringtonensis* (Figs 2-6) were recorded on a 10 m high tree of *Acacia irrorata* growing in montane eucalypt open forest on granite at Mt Mackenzie, Tenterfield, NSW (1280 m) (Fig. 1) on 8 October 2016. Twelve eggs were collected on the foliage of the larval food plant – all eggs were freshly laid singly, either on the underside of the pinnae or leaf rachis of the bipinnate foliage. A total of 30 pupae and 10 pupal exuviae were collected from under a large slab of bark near the base of the trunk of the food plant and from inside a decaying dead eucalypt branch on the ground adjacent to the food plant. A freshly emerged female was photographed settled on the trunk of the food plant drying its wings about 1.5 m from ground level (Fig. 6). The larval attendant ant *Anonychomyrma biconvexa* was abundant on the host tree and on nearby mature eucalypts. *Acacia irrorata* was noted to be a dominant component of the understorey at this site; no other *Acacia* species were present in such abundance.

Acacia binervata DC. (Fabaceae)

Voucher M.F. Braby 202 (CANB)

The immature stages of *P. chlorinda chloris* were recorded on *Acacia binervata* at two sites in the Wollongong district, NSW: (1) Harry Graham Drive approximately 2 km W of Mt Keira (490 m) on 16 April 2017; and (2) Mt Keira (460 m) on 20 January 2018. On both occasions the larval food plant comprised tall shrubs or small trees growing in tall open forest with rainforest elements in the understorey. At the first site, the immature stages were discovered on two trees of *A. binervata* growing on a ridge: four pupal exuviae were recorded low down under bark on the trunk of an 11 m high tree and a single pupa and many old pupal exuviae (from the previous season) were recorded nearby on a second 9 m high senescent tree – all pupae were located under bark in a large dead and decaying stem that had fallen away

Figs 1-6. *Pseudalmenus chlorinda barringtonensis* at Mt Mackenzie, Tenterfield, NSW: (1) montane eucalypt open forest habitat; (2) eggs on underside of pinnae of larval food plant *Acacia irrorata*; (3-4) pupae and pupal exuviae under bark near base of trunk of *A. irrorata*; (5) pupae and pupal exuviae inside decaying dead eucalypt branch on ground; (6) freshly emerged female drying its wings on trunk of *A. irrorata* tree. Photos by J.J. Armstrong.

from the main trunk. The larval attendant ant *Anonychomyrma biconvexa* was present on both *Acacia* trees but the ant colony was particularly abundant on a large tree of *Eucalyptus saligna* Sm., which grew in close proximity to the two *Acacia* host trees. At the second site, 14 pupae were recorded near the summit: a cohort of five pupae was collected under loose fibrous bark (*ca* 1 m from ground level) of a *Eucalyptus sieberi* L.A.S.Johnson tree that grew in close proximity to *A. binervata*; another cohort of seven pupae (2 live, 5 dead) was collected from under loose fibrous bark (*ca* 2 m from ground level) of a second tree of *E. sieberi* growing in proximity to two tall shrubs of *A. binervata*; and two pupae were collected (*ca* 2-3 m from ground level) under bark on the trunk of a large, mature 10 m high tree of *A. binervata*. At this second site, all *Acacia* host trees and, especially, the adjacent eucalypt trees supported substantial colonies of the larval attendant ant *Anonychomyrma biconvexa*. No other species of *Acacia* grew in the vicinity of the breeding site. At both sites, the ants did not attend the pupae.

Discussion

The two new larval food plants reported here for *P. chlorinda* bring the present list of plants recorded for this butterfly to 11 species of *Acacia*. The record of *Acacia irrorata* from northern NSW confirms the listing of this species by Moss (2010). This species is similar to other bipinnate species, particularly *A. mearnsii* and *A. trachyphloia*, and it might have been confused previously with these species. *Acacia irrorata* is distinguished from *A. mearnsii* by having only one or a few glands at the end of the rachis at the base of the pinnae; the rachis is also ribbed with scabrous ridges. *Acacia binervata* is most similar to *A. melanoxylon* and it too might have been confused with this species in the past – indeed the immature stages of *P. chlorinda chloris* were found breeding on *A. melanoxylon* nearby at Mt Kembla, NSW. Both of these species have more than one vein along the face of the phyllode but in *A. binervata* the phyllodes have only two prominent veins, a prominent marginal gland near the base and the apex of the leaf more pointed (acute). The seedpods of the two species are also distinct: in *A. binervata* they are relatively straight and flat, whereas in *A. melanoxylon* they are twisted and coiled.

It is well known that *P. chlorinda* requires three critical resources for its survival: (1) the appropriate larval food plant (*Acacia* spp), (2) the larval attendant ant *Anonychomyrma biconvexa* and (3) large mature eucalypts growing in proximity to the *Acacia* food plants, which are used as pupation sites (*e.g.* Couchman and Couchman 1977, Prince 1993, Wragg and Elgar 1997, Braby 2000). However, one aspect of this complex 4-way ecological association that is not well understood is the ecology of the attendant ant and its relationship with large eucalypts. There seems to be no dependency on a particular age class of the *Acacia* larval food plant, with saplings to very large trees (>10 m high) being utilised by the butterfly and attendant ant. In

our experience, however, the attendant ants are found predominantly on tall (25-40 m high), mature *Eucalyptus* species with large trunk diameters (up to 1.5 m dbh) and hollowed limbs in the crown. In addition to *E. saligna* and *E. sieberi* noted above, we have found ant colonies of *A. biconvexa* on both large smooth-barked (*E. viminalis, E. regnans* and *E. pauciflora*) and rough-barked (*E. obliqua*) trees occupied by *P. chlorinda* (*i.e*. pupae) on the mainland. The ages of these eucalypt trees are not known but, given their immense size and condition, many are probably hundreds of years old. The ants typically occur in large colonies comprising thousands to tens of thousands of workers and they form conspicuous vertical foraging trails along the trunk that extend to the crown of the tree. It is not clear where the ants nest, but it is very likely they do not breed in the *Acacia* food plants. Shattuck (1999: 64) stated that 'Species of *Anonychomyrma* nest either in the ground…or arboreally in living or dead wood.' Wragg and Elgar (1997) postulated that *Anonychomyrma biconvexa* establishes colonies in the hollow trunk of the eucalypt tree, but it is also possible that they are arboreal, nesting in hollowed branches near the crown of the tree. We have never found ant brood or the queen under loose bark near the base of the eucalypt tree, nor on the *Acacia* larval food plant in cases in which the butterfly breeds on large mature trees. The butterfly larvae pupate in a variety of situations, including inside borer holes and under bark of the larval food plant (particularly when they comprise old mature trees – Figs 3-4) and in loose rolled bark, under stones and inside logs and branches at or near the base of the food plant. However, they also pupate under the loose deciduous or persistent bark near the base of mature eucalypt trees (up to 10 m distant from the nearest *Acacia* food plant and up to at least 2 m from the ground) but only on those trees that are occupied by 'massive' colonies of the attendant ant. Presumably, the larvae follow or are shepherded by the ants along the attendant ant trails leading from their *Acacia* food plants to the eucalypt tree.

Clearly, from a conservation management standpoint, the ecological requirements of the attendant ant of *P. chlorinda* and the ants' apparent dependency on old mature eucalypt trees should be investigated as a matter of priority. It is very likely that *Anonychomyrma biconvexa* requires large eucalypts for survival (*i.e.* for food, shelter and breeding) and thus it has the potential to be an indicator species of old growth forest/woodland or of habitats supporting very old living trees, but there is a general lack of basic natural history. In other words, the primary function of mature trees is that they provide a critical ecological resource for *A. biconvexa* – they can serve as pupation sites for *P. chlorinda* but this is probably a secondary function in the overall ecology of the butterfly, given that larvae frequently pupate in a variety of other situations and substrates, at least in natural habitats that have not been severely disturbed. The susceptibility and loss of extant colonies of *P. chlorinda* to removal of mature trees through habitat loss (broad scale clearing) for the pastoral, timber and woodchip industries and frequent fires

has been well documented in Tasmania (Couchman and Couchman 1977, Prince 1993, Sands and New 2002, New 2011).

Acknowledgements

We thank David Albrecht (Australian National Herbarium, Canberra) for identifying the *Acacia* larval food plants of *Pseudalmenus chlorinda* subspecies and Steven Brown for observations on the ecology of the butterfly.

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NESTING BIOLOGY OF *MEGACHILE IGNITA* SMITH, 1853 (HYMENOPTERA: MEGACHILIDAE) IN ARTIFICIAL NESTING BLOCKS IN URBANISED SOUTHWESTERN AUSTRALIA

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Abstract

Bees require floral resources in the form of pollen and nectar for food but, in addition, many cavity-nesting species require other plant resources for nesting materials, which might come from plants on which they do not forage for food. This paper records the habitual use of dry flowers and indumentum from tomentose floral bracts of *Banksia* as nesting material by the Australian megachilid bee *Megachile ignita* Smith, which appears to be characteristic of this species. Additional aspects of its nesting biology are discussed, including phenology, number of brood cells per nest, mortality rate, sex ratio, body size and infestation of nests by parasitoid wasps.

Introduction

Artificial nesting blocks, known as bee blocks or trap nests in the literature, are recognised as useful for boosting populations of cavity-nesting Hymenoptera, for monitoring these taxa and for engaging the public in native bee conservation (MacIvor 2016, Dainese *et al.* 2017, Krombein 1967, Tscharntke *et al.* 1998). Monitoring them can provide insights into the nesting behaviour of native bees. Here, I describe nesting behaviour of the megachilid bee *Megachile ignita* Smith, 1853 in artificial nesting blocks installed around Perth, an urbanised region in south-west Western Australia.

Megachile ignita belongs in the Megachilidae, a large family with numerous subgenera. It was placed in the subgenus *Hackeriapis* Cockerell by Michener (1965) but was left unplaced when King (1994) restricted the concept of that taxon. The presence of a large medial apical spine on S1 suggests that this species should be placed in subgenus *Austrochile* Michener (Michener 2007).

The Megachilidae comprises species that are predominantly above-ground cavity nesters, utilising preformed holes – mainly abandoned tunnels made by wood-boring beetles in trees – but also appropriately-sized cavities in anthropogenic materials (Halcroft and Batley 2014). The materials used to build partitions between cells (if present) and cap the completed nest are diverse and include resin, mud, pebbles, sand, leaves, petals and even plastic particles (Horne 1995, Paini 2004, MacIvor and Moore 2013, Gess and Roosenschoon 2017). Documenting the materials used by bees in nest construction can aid in ensuring suitable nesting materials are available to support bee populations. Although much attention has focused on food provisions, nesting substrates are just as critical to the reproductive success of bees (Potts *et al*. 2005). Here, the nesting biology of *M. ignita* is described, including the use of *Banksia* flowers and indumentum from the tomentose floral bracts (the compressed downy material that covers the central spindle

of a *Banksia* inflorescence, hereafter referred to as *Banksia* indumentum) as nesting materials. Use of these items was found to be a characteristic nesting behaviour of this species not observed in other megachilid nests collected. This is the first example, to the author's knowledge, of megachilid bees using these materials inside their nests.

Methods

Artificial nesting blocks were set up in urban bushland remnants and residential gardens (seven sites per habitat type) in Perth, the largest urbanised region of the south-west Western Australian biodiversity hotspot. Trap nests were monitored monthly from Dec-Feb 2016/17 (season one) and Nov-March 2017/18 (season two).

At each site, eight nesting blocks were installed on tree branches at about 1.5 m height. The blocks were of untreated Jarrah (*Eucalyptus marginata* Smith, 1802) wood measuring 200 mm x 100 mm x 100 mm. Inserted into holes drilled in each block were 15 cardboard bee tubes (Custom Paper Tubes Inc., Cleveland, USA), 12 cm long, five each of 4 mm, 7 mm and 10 mm bore diameter. During monthly visits to each site, tubes containing completed bee nests (evidenced by entrance closures) were removed and replaced with new tubes. Tubes containing nests were maintained in individual perforated plastic take-away containers in the laboratory to develop at room temperature and monitored every few days to record bee emergences.

Bee tubes collected in season one from which progeny did not emerge prior to autumn, were X-ray photographed with a Faxitron X-ray machine in August and July 2017 and then again in April 2018.

For bee tubes containing *Banksia* material, the type of material (flowers and/or indumentum) was recorded. When adults emerged the bees were identified (with the aid of Dr Terry Houston of the West Australian Museum) as *Megachile ignita*. Other data recorded included emergence date, number of progeny per nest, their sex and body size, measured as intertegular distance (linear distance between the insertion points of wings: Cane 1987).

Pollen preferences of *M. ignita* were determined by recording the plants that bees were foraging on for three hours during each visit to trap-nest sites. In addition, the pollen preferences of *M. ignita* were examined by imaging pollen provisions within the collected bee tubes with a Scanning Electron Microscope at 1000x magnification and identifying it by reference to pollen collected from flowers at each site. Four replicates of pollen from four bee tubes, from four separate sites, were examined.

Observations and discussion

During collection of occupied bee tubes, *Banksia* material was observed to have been incorporated into the caps of a number of bee tubes. This material included dried flower parts and indumentum (Figs 1-2). Two tubes collected

on 13 February 2017 that incorporated *Banksia* flowers each yielded a single adult of *Megachile ignita*: the first being a male on 3 March 2017 and the other a female on 8 March 2017 (Figs 3-4). Dissection of the tubes revealed that each had only a single brood cell, with the remainder of the tube being filled with loosely packed *Banksia* flower material (Fig. 5).

Figs 1-4. (1-2) *Banksia attenuata* flower heads showing (1) dried-out flowers and (2) fur-like indumentum exposed on central spike after flowers are shed [Photos by Robert Davis]; (3-4) *Megachile ignita*: (3) female; (4) male [Photos by author].

The identity of the dried floral parts as the dried-out stamens and perianths of *Banksia* flowers was confirmed using a compound light microscope, in consultation with botanist Dr Marion Cambridge of the University of Western Australia. In addition to *Banksia* flowers, masticated leaf material and resin were also used in the cap of the bee tube nest. Although species identity could not be confirmed based on the flower material, the only *Banksia* species at the site was *Banksia attenuata* Brown, 1810. The identity of the indumentum material was also confirmed as from *Banksia* species in consultation with Dr Cambridge.

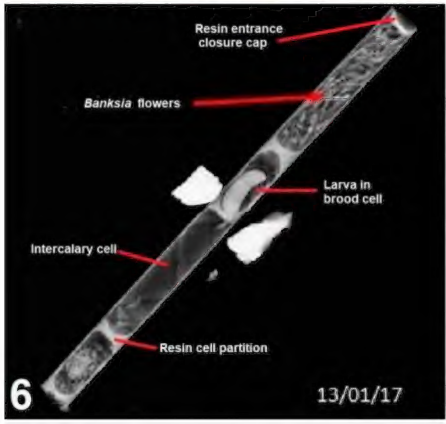
X-ray photography of season one bee tubes from which progeny did not emerge prior to winter, revealed further instances of *Banksia* material being incorporated into the nests of 15 tubes collected on separate surveys from December to February. All had the outermost part of the tube filled, to varying extents, with *Banksia* indumentum (*e.g.* Figs 6-7).

A total of 19 bee tubes from season one and 42 bee tubes from season two contained *Banksia* material comprising flowers (Fig. 6), indumentum (Figs 7-8) or both. In season one, 12 tubes contained flowers, 6 contained indumentum and one contained both materials. In season two, the majority (24 tubes) contained indumentum, with 10 containing flowers and 8 containing both materials. Of the 19 bee tubes containing *Banksia* material from season one, only four had progeny that successfully emerged, each yielding a single bee. Bee tubes collected in season two were not X-rayed but, by March 2018, 42 bee tubes containing *Banksia* material yielded young adults of *Megachile ignita*. Only a single *M. ignita* emerged from a bee tube that did not contain *Banksia* material.

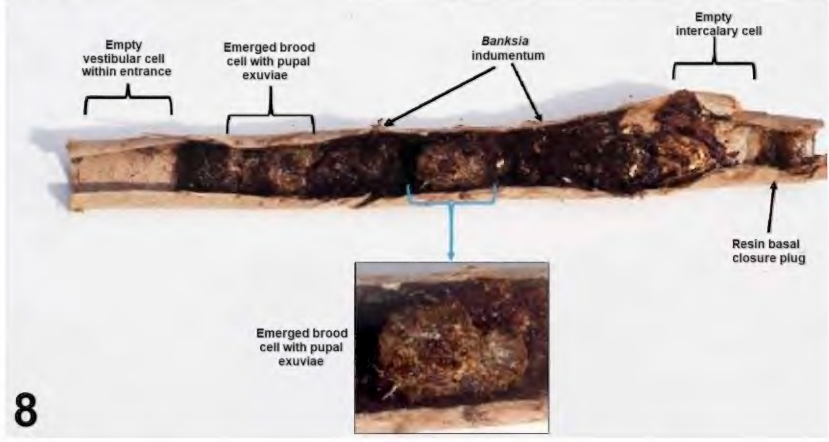
Banksia material was used in all except one of the 62 nests across five sites from which *M. ignita* emerged, whereas none of the other 451 bee tubes (236 from season one and 215 from season two) from which megachilids of ten other species emerged included *Banksia* material. It therefore appears that *M. ignita* has a strong preference for *Banksia* as nesting material and this is a diagnostic nesting character for this species. Noting whether there are instances of this species nesting where *Banksia* is not available will reveal how reliant *M. ignita* is on *Banksia* materials in its nest.

Figs 5-8. 7 mm bee tubes with nests of *Megachile ignita*: (5) two opened tubes showing *Banksia* packing material and two emerged *M. ignita* (♀ left, ♂ right); (6-7) X-ray photographs of tubes from Bold Park, Perth, showing inner cells and packing within entrance of (6) *Banksia* flowers and (7) *Banksia* indumentum; (8) nest tube from Star Swamp, 10 Nov 2017, opened lengthways, containing five provisioned cells, an empty vestibular cell within the entrance at left, and an empty intercalary cell. Inset shows cell with an emerged cocoon. See text for details [Photos by author].

5


Resin entrance closure cap
Banksia flowers
Larva in brood cell
Intercalary cell
Resin cell partition
6
13/01/17

Banksia indumentum
7
13/01/17


Empty vestibular cell within entrance
Emerged brood cell with pupal exuviae
Banksia indumentum
Empty intercalary cell
Resin basal closure plug
Emerged brood cell with pupal exuviae
8

In addition to the novel *Banksia* packing material inside the nests, other aspects of nest architecture for this species are shown in Figs 6-8. These include a nest entrance closure of resin, sometimes incorporating *Banksia* flowers or indumentum. Partitions between cells are comprised of resin approximately 1-2 mm thick, with the basal end of the nest often having a larger resin plug, ranging from approximately 3-13 mm thick. Empty vestibular cells within the entrance and intercalary cells between brood cells can also occur. The cocoons are comprised of a brown parchment-like material and can have dark brown pellets of larval faeces on the outside and be surrounded by *Banksia* packing material on both sides (Fig. 8, inset).

With the larger number of emerged progeny of *M. ignita* in season two, pooling the data from both seasons provided an adequate sample size for elucidating further parameters of nesting biology of this species.

With only two of the 61 *M. ignita* bee tubes having a diameter of 10 mm, and none in the 4 mm tubes, it appears this species prefers to nest in 7 mm diameter tubes.

In season one, most occupied tubes were collected in February, followed by January, with the least in December (Table 1). None of the February bee tubes yielded offspring, while three tubes which completed in January and one in December did so. In season two, with collections occurring over a longer period, most occupied bee tubes were collected in December, the month with fewest completed nests in the previous year (Table 1). The month in season two with the second highest occupation numbers was November, with only one collected in October, two in January and one in February. None was completed in March (Table 1). With only two years of data collection, one can only speculate on the reason for this difference; however, the winter of 2016 had below average rainfall, whereas 2017 had above average rainfall (Bureau of Meteorology 2018), causing plants to flower earlier than in 2016.

Table 1. Percentages of completed nests of *Megachile ignita* in bee tubes collected in each month out of the total number of bee tubes for each season. Note that in season one, trap nests were not monitored in October, November and March.

Month	Season one (n = 19)	Season two (n = 42)
October	-	2.38%
November	-	28.6%
December	10.5%	61.9%
January	47.4%	4.76%
February	42.1%	2.38%
March	-	0%

Combining data from both seasons for bee tubes from which progeny emerged, average number of compartments per tube was 4.88 ± 0.25 (range 2-7); however, only 65.4% ± 0.03 of these were provisioned (the remainder being empty vestibular and intercalary compartments: Krombein 1967), such that the average number of brood cells was 3.35 ± 0.27 (range 1-6) (Fig. 8). Of these provisioned cells, mortality rate was 0.16% ± 0.05, such that on average 3.04 ± 0.03 bees emerged per tube. With a male:female sex ratio of 1.22:1 (n = 137), the sex ratio was biased towards males (exact binomial test: p = 0.028).

Based on progeny that emerged from nests, males of *M. ignita* are significantly larger than females (Welch two sample t-test: t = 5.38, d.f. = 47.3, p = 2.26 x10^{-6}). Average body size (measured as intertegular distance) was 3.58 ± 0.05 mm (n = 30) for males and 3.25 ± 0.03 (n = 26) for females. This contrasts with the majority of bee species, where females are the larger sex (Alcock and Houston 1996, Shreeves and Field 2008).

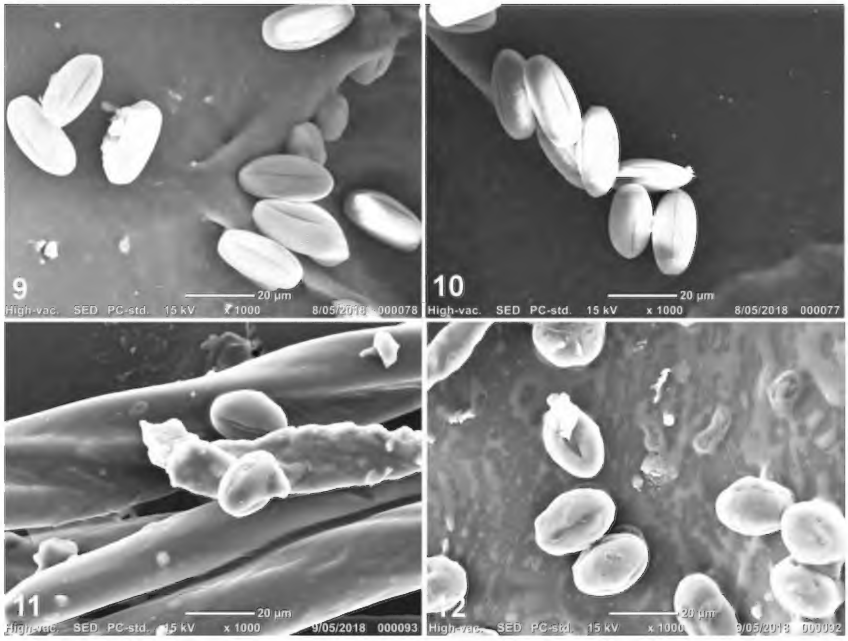
Seven out of the 61 bee tubes were parasitised by wasps: *Melittobia* – gregarious ectoparasitic parasitoids (Dahms 1984) and gasteruptiids – kleptoparasitic predator-inquilines (Jennings and Austin 2002). One bee tube was parasitised by *Melittobia australica* Girault, 1912 (Eulophidae) in season one, resulting in no *M. ignita* completing development. The remainder were parasitised by *Gasteruption* sp. (Gasteruptiidae): two in season one, from which no *M. ignita* emerged; and four from season two, of which three still had *M. ignita* cells that escaped attack and resulted in offspring completing development.

Other species of megachilids are known to create barricades from plant material, located towards the entrance of the nest, which are believed to function in keeping predators and parasitoids from reaching the brood cells. For example, *Megachile* (*Schizomegachile*) *monstrosa* Smith, 1868 creates a large plug made from masticated plant material (Houston 2018) and *Lithurgus* (*Lithurge*) *atratiformis* Cockerell, 1905 creates a 9 mm long barricade of fine wood particles to block the nest entrance (Houston 1971). Whether the *Banksia* material in *M. ignita* nests also serves to deter predators and parasitoids is unclear, given the relatively loose nature of the material.

The only other known instance of bees using *Banksia* material was a single observation of *Megachile aurifrons* adding *Banksia* indumentum into the cap of a nest built in a gum nut (the woody fruits of Myrtaceae) (Houston 2018). However, it appears this behaviour is idiosyncratic for *M. aurifrons,* rather than a characteristic feature as is the case for *M. ignita. Megachile aurifrons* nested in 22 bee tubes during my study but none had *Banksia* material in them and nest seals were composed of masticated vegetation.

Despite *Banksia attenuata* flowering in abundance at sites where these bee tubes were collected, during my surveys no megachilids (*M. ignita* or other

species) were observed foraging on them. Indeed, every observation in the field of *M. ignita*, both males and females, involved them foraging on one of three species of *Jacksonia* (Fabaceae), *viz*. *J. furcellata* Bonpland, 1825, *J. sternbergiana* Hügel, 1837, and *J. sericea* Bentham, 1864. The exclusive preference of *M. ignita* for Fabaceae, based on foraging observations, was corroborated by examining pollen from trap nests microscopically (Figs 9-12). These observations are consistent with previously reported flower-visiting records for *M. ignita* (Houston 2000), the majority of which are to *Jacksonia* species. As females only visit old *Banksia* conflorescences to gather nest material, they are unlikely to affect pollination of any fresh *Banksia* flowers.



Figs 9-12. Scanning electron microsope images at 1000x of polllen collected from: (9) *Jacksonia furcellata* in the field; (10) *Jacksonia scoparia* in the field; (11-12) pollen residue in nest tubes of *Megachile ignita* from (11) Jandakot, Perth on 2 Dec 2017 and (12) Star Swamp, Perth on 10 Dec 2017 [Photos by author].

Remnant *Banksia* woodlands are habitats of high conservation importance for supporting a diversity of wildlife, especially around Perth, where much natural habitat has been cleared (Cox and Underwood 2011). These observations further the case for protecting remnant *Banksia* bushland in an urbanised region and show that, despite *M. ignita* not utilising *Banksia* for food resources, *Banksia* flowers nevertheless form an important resource for this bee species.

Acknowledgements

The project was part of the author's PhD project at Curtin University in Perth. The author would like to express her appreciation to the Perth residents who permitted her to survey their properties for native bees, to the WA Museum for permitting her to use their photographic microscope, to Dr Terry Houston (bee taxonomist and former curator of Entomology at the WA Museum) for his taxonomic assistance and helpful comments as a reviewer for the manuscript, to Dr Michael Batley for his review comments on the manuscript, to Liz and Stephen Prendergast for their assistance in installing the bee hotels, to Dr Bill Bateman for his support, to Dr Geoff Monteith for his thorough and expert editorial comments and to Mark Donald for inspiring the author.

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THE MECOPTERA OF THE PALEOGENE REDBANK PLAINS FORMATION, SOUTHEASTERN QUEENSLAND

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Abstract

The Redbank Plains Formation is a southeastern Queensland Paleogene sequence that has yielded a diverse assemblage of fossil insects, including two mecopterans, *Chorista sobrina* Riek (Choristidae) and *Austropanorpa australis* Riek (Austropanorpidae). New specimens as well as a re-examination of the original type material provide additional information on the venation of both species, confirming the six-sided M-CuA cell as the diagnostic character for *C. sobrina*. Not withstanding the additional venational information on *A. australis*, the type species of the type genus of the Austropanorpidae, with only the forewing and half a hind wing to work with, the position of the family in the scheme of the Mecoptera remains unresolved.

Introduction

Fossil insects have now been known from the Paleogene Redbank Plains Formation of south-east Queensland for over 100 years. They were discovered around 1913 by Lionel C. Ball, a geologist with the Geological Survey of Queensland, who collected a fragmentary lacewing hind wing in 'clay ironstone' of a 'Tertiary deposit' exposed on portion 172, parish of Bundamba (Dunstan 1916, but with the parish incorrectly quoted as Goodna). The Formation has since produced a diverse assemblage of fossil insects, mostly fragmentary wings or elytra, and the fauna has a distinctly modern facies. Works by Tillyard (1916, 1923), Riek (1952, 1954, 1967) and Lambkin (1987, 1992) have now described or recorded additional specimens of a total of 11 species in the Neuroptera, Hemiptera, Mecoptera, Isoptera, Orthoptera, Diptera and Megaloptera.

Through the dedicated collecting of Alan Rix of the University of Queensland at the original locality discovered by Ball, a substantial amount of new fossil insect material is now available, generously donated to the Queensland Museum by Professor Rix. The Rix collection includes well preserved specimens of the two mecopterans described from the Formation by Riek (1952, 1967), *Chorista sobrina* Riek (Choristidae) and *Austropanorpa australis* Riek (Austropanorpidae). The specimens provide new data on the venation of the two species and the opportunity is therefore taken herein to re-examine both species in the light of this new data and more recent advances in our knowledge of the two families.

The Redbank Plains Formation is a sequence of mudstone, claystone, shale and sandstone averaging 67 m thick, with very limited surface exposures in the Ipswich suburbs of Redbank Plains and Dinmore (Cranfield *et al.* 1976, Cook 2013). All the specimens examined herein are preserved in ferruginous mudstone collected at the Formation's 'type locality' (Riek 1952), the same locality originally discovered by Lionel C. Ball. In more recent times much

of the locality has been cleared for residential development but, fortunately, a substantial part has been preserved as the Ipswich City Council's 'Jones Road Reserve', with Queensland property description, Lot 171, Registered Plan 904872, located at approximately -27.654°152.874° (Alan Rix pers. comm.). The other major collecting locality in the Formation was a now inaccessible clay pit in the Ipswich suburb of Dinmore. The lithology there was soft grey shale, a quite different matrix to that of the type locality. Although Riek (1952) stated that the Dinmore insect fauna was quite different from that of Redbank Plains, subsequent collecting has demonstrated that there are some similarities, at least in the Orthoptera, Hemiptera and Neuroptera. The age of the Redbank Plains Formation is not certain but the fact that it conformably underlies the Silkstone Formation (Cook 2013), the basal basalts of which have been dated at around 45 Ma (Green and Stevens 1975), suggests an early Eocene age, noting that the Paleocene/Eocene boundary is set at 56 Ma.

All specimens examined are wings, which range in preservation from almost entire to fragmentary. Specimens that have both part and counterpart have 'a/b' in their registration numbers, otherwise the part only is present. The line drawings were prepared using a camera lucida attachment on a Motic stereomicroscope. To facilitate comparison, all specimens are figured as right wings. The photographs were focus stacked with Zerene Stacker software from source images taken with a Canon 5D MkII or 5DS camera on a Visionary Digital BK-Plus Lab System. All specimens are in the Queensland Museum and are prefixed by either QMF (Queensland Museum Geosciences) or UQF (University of Queensland Geology Department), the latter collection having been transferred to the Museum in 1999.

Systematics

Family Choristidae Esben-Petersen, 1915

Genus *Chorista* Klug

Chorista Klug, 1838: 87. Type species *C. australis* Klug, by monotypy.

Forewing diagnosis. Quite narrow, at least 4 times longer than wide; costal space without costal veinlets; R1 fork at least at same level or more usually proximal to that of R2+3; pterostigma distinctly defined; anal veins fairly straight and more or less parallel, simple or with terminal forks; anal field with five or fewer crossveins.

Notes. Only the forewing is available for the Redbank Plains species. Extant Choristidae comprise three genera, *Chorista* (two species), *Taeniochorista* Esben-Petersen (four species) and *Meridiochorista* Lambkin (two species) (Lambkin 1996). The above forewing diagnosis is based on an examination of the substantial holdings of the Australian National Insect Collection and the Queensland Museum of *Chorista australis* Klug, *C. luteola* (Westwood), *Taeniochorista pallida* Esben-Petersen, *T. bifurcata* Riek and *Meridiochorista ruficeps* (Newman), as well as the forewing figures of all

extant species in Riek (1973). The species of *Taeniochorista* have a broader wing (no more than 3.5 times longer than wide), at least two and usually more costal veinlets, the R1 fork distinctly distal to that of R2+3, a weakly defined pterostigma, and a complex networked anal field with 2A bent towards or fused for a short distance basally with 1A and with at least six and usually more crossveins. The forewing of the third genus, *Meridiochorista*, is quite similar to that of *Chorista*, but differs in having a weakly defined pterostigma (a feature not preserved in the Redbank Plains material) and, at least in its type-species, *M. ruficeps*, the R1 fork distinctly distal to that of R2+3, rather than at least at the same level or more usually proximal as in both species of *Chorista*. The characters of the Redbank Plains fossil forewing are therefore consistent with the forewing diagnosis of *Chorista*, and the species is retained in that genus.

***Chorista sobrina* Riek**

(Figs 1-2)

Chorista sobrina Riek, 1952: 10, text-fig. 1, plate 1, fig.1.

Material examined. *Holotype* UQF10628a/b, almost complete forewing; *paratype* UQF10630a/b, forewing apical fragment; *paratype* UQF10632a/b, ? hind wing apical fragment; QMF52358a/b, well preserved almost complete forewing; QMF44793a/b, indistinctly preserved forewing fragment. All Redbank Plains 'type locality'.

Diagnosis. Forewing approximately 16 mm long, 3.8 mm wide; M4 deeply forked (at level of R4+5 fork), the basal cell between M and CuA six-sided, bounded apically by the stem of M3+4, the very short stem of M4, the very short upright stem of M4b, and the short, oblique crossvein between M4b and CuA; all anal veins simple, with only two crossveins detected; crossveins less numerous than in extant species (although this might be due to poor preservation in the coarse matrix).

Notes. The deeply forked M4 with the resultant six-sided M-CuA cell is unique in the Choristidae and is the species' most obvious diagnostic feature. In other choristids the cell is four- or five-sided, the stem of R4b not forming part of its apical boundary. It may have been considered that with such an unusual structure, the holotype was simply an aberrant individual, however, the form of the M-CuA cell is identical in the second well-preserved forewing (QMF52358a/b). The two well-preserved forewings (the holotype and QMF52358a/b) both appear to have a narrow costal space and an almost straight costal margin. This is almost certainly a preservation artefact as all extant choristids have the space expanded and the margin consequently broadly convex. Paratype UQF10632a/b, an apical fragment, is slightly smaller than the other specimens and is possibly a hind wing.

The species was described in detail by Riek (1952). Examination of the new forewing, QMF52358a/b, as well as a careful re-examination of the holotype, have now provided information on the anal veins and the base of Cu, as well

as identified a number of crossveins additional to those figured by Riek (see Fig. 2). In regard to crossveins, those figured by Riek between M2 and M3, and between M3 and M4, could not be detected in the present study.

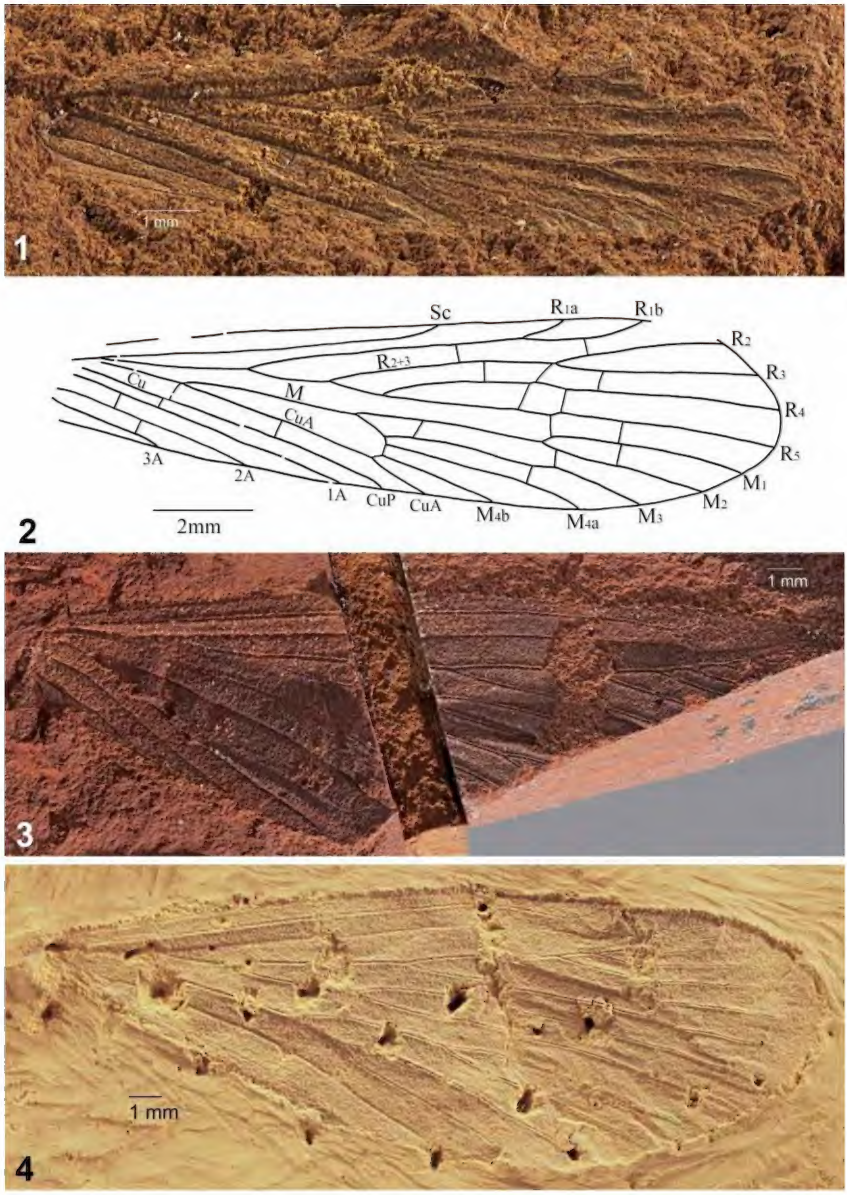
Family Austropanorpidae Willmann, 1977

Type genus. *Austropanorpa* Riek, 1952: 11.

Diagnosis. Wings broad and of large size, forewing 3 times longer than wide, at least 25 mm long, hind wing narrower and of smaller size; fore- and hind wings with R2 extensively pectinate, with six branches; R3, R4 and R5 simple; M with four simple branches.

Notes. Riek (1952) assigned *Austropanorpa* to the Panorpidae on the basis of the four-branched M and the absence of any basal fusion of CuA and the stem of M in the forewing. Willmann (1977) undertook an extensive analysis of the genus, drawing attention to the wing colour pattern, the large pterostigma, the pectinate R2, the broad wing and wing base, the four-branched M, and the free course of CuA in the forewing. As a result of this analysis he established the new family Austropanorpidae, with the extensively pectinate R2 and the large wing size as its autapomorphies. In his subsequent phylogenetic analysis of the Mecoptera, Willmann (1987) associated the family with the extant Panorpidae and Panorpodidae in his Panorpoidea, on the grounds of the apomorphic loss of the M4b to produce the four-branched M in the forewing, although noting that he considered the loss in the Austropanorpidae as due to convergence. Novokshonov (2002), presumably on the basis of the pectinate R2, tentatively assigned *Austropanorpa* to the extinct mecopteran family Orthophlebiidae, while Archibald *et al.* (2013) accepted the family status of Austropanorpidae and again associated it with Panorpidae+Panorpodidae on the loss of M4b. Krzemiński *et al.* (2017) assigned a Siberian Jurassic species to *Austropanorpa*, *A. martynovae* (Sukatsheva, 1985), and provided diagnoses and redescriptions of the family, genus and the two known species. The family diagnosis given above is consistent with that of Krzemiński *et al.*, except that it also includes reference to the large size and breadth of the wings, as noted by Willmann (1977). *Austropanorpa martynovae* was based on a single specimen of a hind wing that, as expected, is somewhat smaller and narrower than the forewing as represented by the type species.

In summary, and as noted by Krzemiński *et al.* (2017), the Austropanorpidae differs from all other Mecoptera in having both wings with R2 pectinately six-branched and M four-branched. The four-branched M in the forewing is shared with both the extant and fossil species of the families Panorpidae and Panorpodidae (Ding *et al*. 2014, Hu and Hua 2016), but whether this character is a symplesiomorphy, a synapomorphy, or due to convergence in the Austropanorpidae, remains uncertain.



Figs 1-4. (1-2) *Chorista sobrina* forewing: (1) QMF52358a/b; (2) composite of QMF52358a/b (extreme base, base of Cu and CuP, and most of anal field) and holotype UQF10628a/b. (3-4) *Austropanorpa australis* forewing: (3) holotype UQF10634a/b (mirrored, and the two segments re-aligned); (4) QMF44905.

Genus *Austropanorpa* Riek

Austropanorpa Riek, 1952: 11. Type species *A. australis* Riek, by monotypy.

Diagnosis. As for the family.

Austropanorpa australis Riek

(Figs 3-6)

Austropanorpa australis Riek, 1952: 11-12, text figs 2-3, plate 1, figs 2-3; Riek, 1967: 71, fig. 1.

Material examined. *Holotype* UQF10634a/b, complete forewing except for postero-apical area; paratype UQF10636a/b, indistinctly preserved almost complete forewing; UQF15572a/b, apical half of hind wing; QMF44815a/b, QMF44856a/b, each the apical ¾ of a forewing without margins; QMF44905 complete forewing except for anal field. All Redbank Plains 'type locality'.

Hind wing diagnosis. Wing quite broad, length from level of primary M fork to apex of wing 2 times wing width; colour pattern comprised of a transverse band from the costal margin extending across r1-r2 and terminating at r5-m1, a small transverse spot between M2 and M4 around 1m2-m3 and m3-m4, and a short transverse band apically between R1b and R3 (Fig. 6).

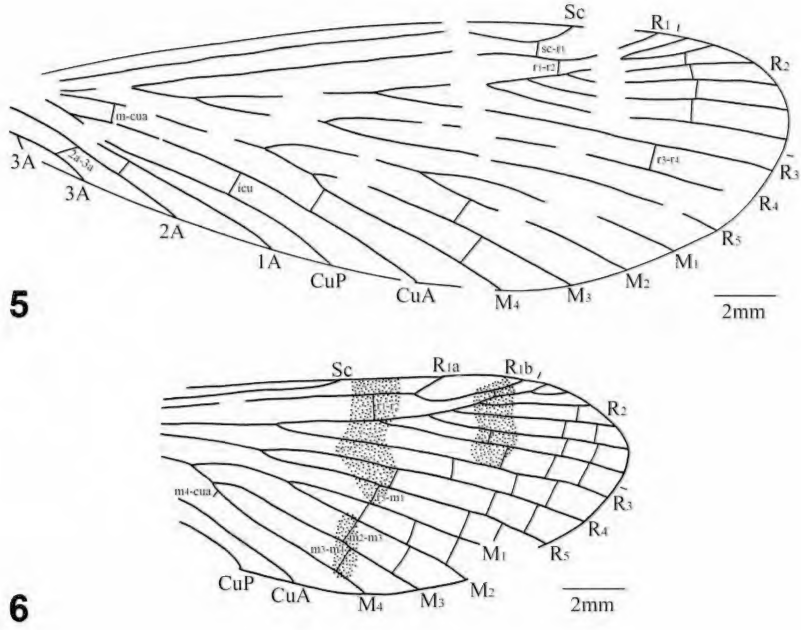
Notes. The diagnosis is restricted to the hind wing as the only comparative species is *A. martynovae*, which is known only from the hind wing. Its wing is somewhat narrower, the length from the level of the primary fork of M to the apex is 2.4 times the width of the wing, and the colour pattern is quite different, comprised of four transverse bands (Krzemiński *et al.* 2017, fig. 3).

Austropanorpa australis has been described in detail by Riek (1952, 1967) and Krzemiński *et al*. (2017). Re-examination of the forewing types, Riek's 1967 hind wing and the three new Queensland Museum forewings, has provided the following additional information:

Forewing (Fig. 5): Length *ca* 27 mm, width 9.1 mm (only measurable in composite of holotype and QMF44905 – Fig. 5). The paratype (UQF10636a/b) is noticeably smaller than the other four forewings (width between R1 at the level of the basal R2 pectinate branch and the hind margin 5.8 mm, compared with 7.8-8.6 mm). Even though the venation, as far as is preserved, is identical with the others, the size difference might suggest another species. It is probably preferable, however, to consider the difference as simply representing intraspecific size variation. The extant *Brachypanorpa sacajawea* Byers, for example, a member of the Panorpodidae (a potential sister family of Austropanorpidae), exhibits size variation of a similar magnitude (Byers 1990). Riek (1952) observed 'a definite break in the vein indicative of a thyridium' in the type material but due to poor preservation this could not be detected in the present study. The base of Cu is preserved in QMF44905. Vein 3A is forked. Crossvein preservation is poor; all those detected are shown in Fig. 5. The 2A-3A crossvein is distinctly inclined. The figures of *A. australis* in Krzemiński *et al*. (2017) were drawn from

photographs and show a series of crossveins basally between the pectinate branches of R2 in the holotype, as well as numerous crossveins in the distal R and M fields of the paratype. None of these was detected in the present study, except for one apical crossvein between R3 and R4 in the paratype.

Hind wing (Fig. 6): Width 7.3 mm. The wing surface in the specimen is glossy except for those areas shown stippled in Fig. 6, which are presumed to represent a wing colour pattern. Eight crossveins (m4-cua incompletely preserved) additional to those illustrated by Riek (1967) were detected.



Figs 5-6. *Austropanorpa australis*: (5) forewing, composite of QMF44905, holotype UQF10634a/b (anal field and basal hind margin, sc–r1, r1–r2, m–cua, and icu) and paratype UQF10636a/b (r3–r4); (6) hind wing, UQF15572a/b.

Discussion

Chorista sobrina from the ?early Eocene Redbank Plains Formation is the earliest confirmed crown choristid. Jell and Duncan (1986) ascribed *Cretacochorista parva* Jell & Duncan from the Cretaceous of Koonwarra, Victoria, to the Choristidae, but that species has a forked R2 and a different wing shape from that of crown choristids (Krzemiński *et al*., 2014, fig.5) and was consequently transferred to the extinct family Orthophlebiidae by Krzemiński *et al*. (2014). Extant Choristidae are now restricted to southeastern mainland Australia, where they occur in the moister zones of eucalypt woodland. The habitat of *C. sobrina* in the ?early Eocene, however,

might have been a little different, as the Redbank Plains Formation fossil flora is dominated by Lauraceae and other rainforest elements that suggest a complex mesophyll-notophyll rainforest environment (Andrew Rozefelds, Queensland Museum, pers. comm.).

Unfortunately, the new material and re-examination of the types of *Austropanorpa australis* can add little to clarify the phylogenetic position of the Austropanorpidae. The family shares the four-branched M in both wings with the Panorpidae and Panorpodidae but, as already mentioned, this character is of uncertain polarity and recent analyses (Whiting 2002, Grimaldi and Engel 2005, p. 469) suggest that Panorpidae and Panorpodidae might not even be sisters. The presumed apomorphic pectinate R2 is shared with the extinct Orthophlebiidae, but this family lacks clear definition and in the words of Soszńska-Maj *et al*. (2018) has become 'a "wastebasket" for many taxa of ultimately unclear taxonomic position'. An admittedly brief survey of the venation of extant Panorpidae and Panorpodidae *vis-à-vis* that of *Austropanorpa* suggests that characters such as the relative length of Sc, its apex straight or concave, R1 simple or forked in the forewing, its apex straight or strongly concave, the relative length of the stem of M3+4, the form of the base of M4, and 3A simple or forked, might possibly be of cladistic value, but any analysis of these would require an intensive study of their status across the Mecoptera, a study beyond the scope of the present work. It must be conceded, however, that as long as we only have the forewing and half a hind wing to work with, the position of *Austropanorpa* in the scheme of the Mecoptera will inevitably remain unresolved. As a final observation, it is pleasant to ponder that *A. australis*, a scorpionfly with 27 mm long and 9 mm wide forewings, must have been a magnificent insect in flight, much like the similarly large-winged mesopsychids of the Queensland Triassic (Lambkin 2014).

Acknowledgements

I am pleased to acknowledge the dedicated collecting of Alan Rix at Redbank Plains and his generous donation to the Queensland Museum. Geoff Thompson of the Museum took the photographs and my daughter, Jennifer Negline, kindly prepared the plates. Kristen Spring of the Museum and Debbie Jennings of the Australian National Insect Collection were unfailingly helpful in making available specimens in their care. I also thank Joanne Wilkinson of the Museum for her expert specimen preparation. Finally, it is an honour to further the work of one of the greatest Australian systematic entomologists, Edgar Riek (1920–2016). Edgar stimulated and encouraged what became my life-long interest in the Mecoptera, which were indeed one of his most loved orders: in his own words – 'The sight of *Harpobittacus* flying leisurely over *Leptospermum* flowers in spring or of *Chorista* or the smaller *Nannochorista* resting on grass tussocks in a sheltered glade in autumn is every true entomologist's joy' (Riek 1975, p. 75).

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A SURVEY OF BUTTERFLIES (LEPIDOPTERA) OF CHRISTMAS ISLAND (INDIAN OCEAN) IN MARCH 2017

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Abstract

A survey of the butterflies of Christmas Island, Indian Ocean, in March 2017 identified 23 of the 29 species recorded for the island. These include the first published records for *Petrelaea tombugensis* (Röber) (Lycaenidae), *Badamia exclamationis* (Fabricius), *Hasora chromus* (Cramer) and *Borbo cinnara* (Wallace) (Hesperiidae), all first taken in 2003 by Ian Knight and still present. Abundance, distribution and larval food plants for each butterfly species are discussed. Rainforests that cover most of the island contained the greatest diversity while the unrehabilitated mined areas had few butterflies. The presence of now common species such as *Papilio memnon memnon* Linnaeus, *Appias olferna* Swinhoe, *Eurema blanda blanda* Boisduval, *Euchrysops cnejus cnejus* (Fabricius) and *Zizina otis* (Fabricius), which were unrecorded prior to 1985, suggests that these species are recent arrivals. The life history of *Papilio memnon memnon* on Christmas Island is illustrated. Observations on yellow crazy ant (*Anoplolepis gracilipes* (Smith)) interactions with some species are recorded.

Introduction

Christmas Island is administered by the Australian Government and located at 10.49°S, 105.63°E in the Indian Ocean. It lies 2650 km northwest of Perth, Western Australia and 380 km south of the nearest other land (Java, Indonesia). Its area is 135 km^2, of which approximately 60% has been declared as Christmas Island National Park (Fig. 1 herein and Fig. 1 in Wilson and Johnson 2017). The national park is managed by Parks Australia. Average annual rainfall is 2670 mm. The island is the summit of a submarine mountain that rises steeply from sea level to a central plateau. The plateau reaches heights up to 361 metres at Murray Hill on the western side of the island and consists mainly of limestone with small areas of volcanic rock exposed. The island's emergence is a result of a series of geological uplifts. The ocean-eroded cliffs at each uplift form stepped terraces from the coast to the island's central plateau. Landscapes of parts of the island are shown in Figs 2-3. Mining of phosphate has been carried out on Christmas Island since the late 1800s and remains a large contributor to the island's economy.

Tall rainforest, with a canopy height to 40 m, covers most of the plateau and terraces where soils are deep. Semi-deciduous forest, with a canopy height of 15-30 m, grows on the shallower soils of the slopes and terraces. Smaller areas of deciduous scrub occur on the steep slopes and inland cliffs. Introduced weeds occupy most of the disturbed mined areas and road corridors. Rehabilitation of mined areas in regions of high ecological significance is being undertaken by Parks Australia.

The history of collecting of Christmas Island butterflies was summarised by Moulds and Lachlan (1987) up to the time of Lachlan's visit in 1985, after which the number of species stood at 22. Moulds and Humphrey (2000)

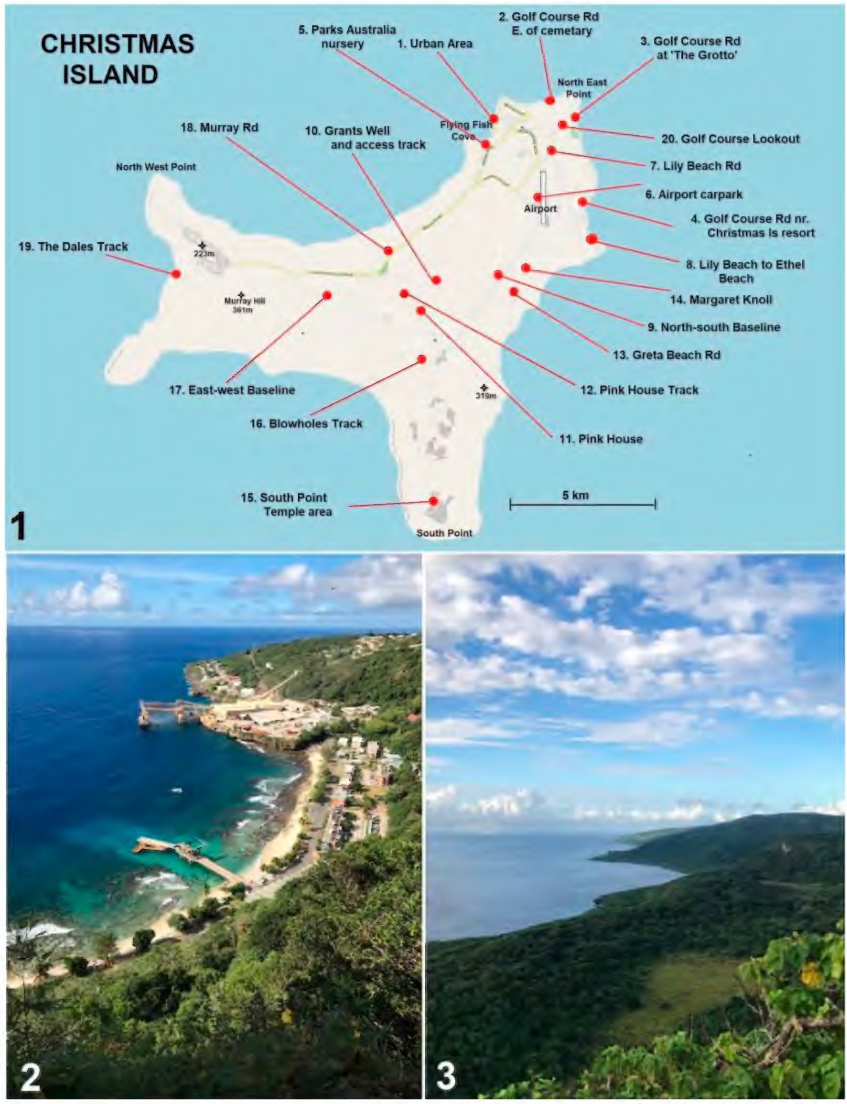
recorded their 1999 collection of *Papilio memnon memnon* Linnaeus. Parks Australia maintains a list of butterfly species that have been recorded on the island up to the present time (Table 1). More recent collections have been by Ian Knight in 2003 (Ian Knight pers. comm., Lambkin and Knight 2004) and a birding group in 2011 (Frank Pierce pers. comm.). Knight added to the Parks Australia list the lycaenid *Petrelaea tombugensis* (Röber, 1886), the three skippers *Badamia exclamationis* (Fabricius), *Hasora chromus* (Cramer) and *Borbo cinnara* (Wallace) and the pierid *Appias olferna* Swinhoe (Lambkin and Knight 2004). Specimens from the Knight visit are held in the Trevor Lambkin and Ian Knight Collection (Brisbane) and Parks Australia on Christmas Island.

Methods

The authors visited Christmas Island for 11 days from 7-18 March 2017, with the primary aims of documenting the butterfly life histories that were unknown or not recorded in Australian territory and undertaking a survey of the occurrence, relative abundance and distribution of the butterflies on the island. Five new butterfly life histories from Christmas Island were described as a result of the visit (Wilson and Johnson 2017) and that of *Papilio memnon memnon* is illustrated in this paper.

Upon arrival on Christmas Island, an initial reconnaissance, with the help of Parks Australia, identified access, landforms and vegetation communities. The authors attempted to visit all vegetation communities over a range of landforms, ensuring that the survey area of each site had a relatively uniform vegetation type and landform. Other than these criteria, the selection of the 20 sites (Fig. 1 and Table 2) was essentially random along roads and tracks where visibility was unrestricted but occasionally was influenced by presence of particular species in certain circumstances, such as the airport car park where butterflies were attracted to flowering plants. Some sites, especially in forested regions, had visibility restricted to 10 metres or less. The sites were distributed over the whole island where access allowed. A limited time was allocated to each site (generally 2-4 hours) to allow an assessment of each of the 20 sites within the 11 days of the visit. Only the Pink House and Margaret Knoll sites were visited more than once, reflecting the greater number of species observed at these sites. Notes on relative abundance at each site were based on subjective observations at that time. Each species (Table 1) collected or sighted at each site from 7-18 March 2017 is allocated an abundance category in Table 3. The abundance categories correspond to those adopted by Braby (2016), where rare (R) = 1-2 adults/1 ha/5-6 hrs; uncommon (U) = 3-10 adults/1 ha/5-6 hrs; common (C) = 11-50 adults/1 ha/5-6 hrs; very common (V) = 51-100 adults/1 ha/5-6 hrs; superabundant (S) = >100 adults/1 ha/5-6 hrs.

Voucher specimens are lodged with the Museum of Tropical Queensland, Townsville, which is a branch of the Queensland Museum, Brisbane.



Figs 1-3. Christmas Island: (1) map showing the 20 butterfly survey sites listed in Table 2; (2) urban area and phosphate loading facility at Flying Fish Cove surrounded by forests on uplifted terraces; (3) east coast looking SE from Margaret Knoll on the edge of the central plateau and overlooking a series of uplifted terraces and an area of introduced weeds on a mined area in centre foreground.

Observations were made on interactions between the introduced yellow crazy ant (*Anoplolepis gracilipes* (Smith)) and the butterflies and their breeding stages, when encountered.

Table 1. List of butterfly species recorded from Christmas Island (Species list source: Christmas Island National Parks, Parks Australia) showing year first recorded. Asterisks indicate the species recorded during March 2017.

Family	Scientific name	Common name	First record
HESPERIIDAE	*1. Badamia exclamationis**	Narrow-winged Awl	2003
	*2. Hasora chromus**	Chrome Awl	2003
	*3. Borbo cinnara**	Rice Swift	2003
PAPILIONIDAE	*4. Papilio memnon memnon**	Malay Swallowtail	1987
	5. Papilio demoleus malayanus	Lime Swallowtail	1961
PIERIDAE	*6. Appias olferna**	Striped Albatross	2003
	7. Appias paulina micromalayana	Yellow Albatross	1932
	*8. Catopsilia pomona**	Lemon Migrant	1940
	*9. Eurema blanda blanda**	Papuan Grass-yellow	1985
	*10. Eurema alitha amplexa**	Scalloped Grass-yellow	1887
NYMPHALIDAE	*11. Charaxes andrewsi**	Christmas Emperor	1897
	*12. Euploea climena macleari**	Climena Crow	1887
	*13. Euploea corinna**	Common Crow	1932
	*14. Hypolimnas anomala anomala**	Crow Eggfly	1932
	*15. Hypolimnas bolina nerina**	Varied Eggfly	1887
	16. Hypolimnas misippus	Danaid Eggfly	1897
	*17. Danaus petilia**	Lesser Wanderer	1897
	*18. Junonia villida**	Meadow Argus	1897
	19. Melanitis leda	Evening Brown	1897
LYCAENIDAE	*20. Prosotas aluta*		1887
	*21. Prosotas dubiosa lumpura**	Purple Line-blue	1964
	*22. Petrelaea tombugensis**	Mauve Line-blue	2003
	*23. Nacaduba kurava nemana**	White-banded Line-blue	1964
	*24. Jamides bochus**	King Cerulean	1975
	25. Catochrysops panormus exiguus	Pale Pea-blue	1975
	*26. Lampides boeticus**	Long-tailed Pea-blue	1975
	*27. Zizula hylax**	Dainty Grass-blue	1932
	*28. Zizina otis**	Common Grass-blue	1985
	*29. Euchrysops cnejus cnejus**	Spotted Pea-blue	2003

Table 2. List of sites and transects on Christmas Island where butterflies were surveyed (shown in Fig. 1).

Survey sites and transects on Christmas Island	**Coordinates (WGS 84)**	**Landscape description**
1. Urban area (including Flying Fish Cove)	-10.4233, 105.6725	Smith Point to Rocky Point and Poon San, highly disturbed, urban
2. Golf Course Road east of the cemetery	-10.4155,105.6914	Undisturbed rainforest on lower coastal terrace
3. Golf Course Road at 'The Grotto'	-10.4227, 105.7016	Undisturbed rainforest on lower coastal terrace
4. Golf Course Road near Christmas I. Resort	-10.4531, 105.7042	Mainly undisturbed rainforest on lower coastal terrace
5. Parks Australia Nursery, Drumsite	-10.4325, 105.6696	Highly disturbed, urban
6. Airport car park	-10.4514, 105.6883	Highly disturbed, urban bordering disturbed forest with regrowth
7. Lily Beach Road	-10.4347, 105.6931	Highly disturbed, previously mined
8. Lily Beach to Ethel Beach	-10.4648, 105.7089	Undisturbed rainforest on lower coastal terrace
9. North-South Baseline	-10.4792, 105.6741	Several transects, undisturbed rainforest on central plateau
10. Grants Well and access track	-10.4811, 105.6521	Cleared area with fruit trees in undisturbed rainforest, central plateau
11. Pink House	-10.4919, 105.6464	Undisturbed rainforest on central plateau
12. Pink House Track	-10.4859, 105.6404	Undisturbed rainforest on central plateau
13. Greta Beach Road	-10.4851, 105.6797	Undisturbed rainforest on middle to lower coastal terraces
14. Margaret Knoll	-10.4767, 105.6840	Undisturbed rainforest, much rock outcrop on edge of central plateau
15. South Point Temple area	-10.5602, 105.6511	Highly disturbed, previously mined
16. Blowholes Track	-10.5095, 105.6468	Undisturbed rainforest on middle to lower coastal terraces
17. East-West Baseline	-10.4865, 105.6130	Revegetated, highly disturbed, previously mined
18. Murray Road	-10.4706, 105.6348	Several transects, undisturbed rainforest on central plateau
19. The Dales track	-10.4789, 105.5592	Undisturbed rainforest on middle to lower coastal terraces
20. Golf Course Lookout	-10.4255, 105.6970	Undisturbed rainforest, much rock outcrop on edge of middle terrace

Table 3. Relative abundance of the 23 butterfly species taken at the 20 collection sites (see Table 2) during the survey. Lettered abundance categories are: **R** (Rare); **U** (Uncommon); **C** (Common); **V** (Very common); blank indicates not recorded. See text for details.

Butterfly Species	Collecting Sites																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. *Badamia exclamationis*	C							U												
2. *Hasora chromus*					U									U						
3. *Borbo cinnara*		U		U					U	C	C	C								
4. *Papilio memnon*	C	U	U	U					C	C	C	C				U	C	U	U	U
6. *Appias olferna*	U	V	C	C	C	C	U	U	C	C	C	C	V	U	U	C	U	C	U	C
8. *Catopsilia pomona*											U									
9. *Eurema blanda*	C	C	V	V	C	U	U	U	C	U	C	C	C	U	U	U	C	C	U	C
10. *Eurema alitha*	C	V	V	C	C	U	U	U	C	C	C	U	U	U	U	U	C	C	U	C
11. *Charaxes andrewsi*									R		U			R						
12. *Euploea climena*	V			U		V			U	U	C	C	U	U		C		U	C	
13. *Euploea corinna*					R															
14. *Hypolimnas anomala*	U	C	C	C	U	V		U	C	V	V	V	V	C		C	C	C	U	C
15. *Hypolimnas bolina*	C	C	U	U	C	V	C	U	C	C	V	V	C	U	C	C	V	C	U	C
17. *Danaus petilia*	U					U				R							R			
18. *Junonia villida*	V	C	C	C	C	V	V	U	V	V	V	V	C	U	V	C	V	V	U	V
21. *Prosotas dubiosa*				U				C	U	U	C	C	U	C					U	
22. *Petrelaea tombugensis*											R									
23. *Nacaduba kurava*											R									
24. *Jamides bochus*			C								C			U	U					
26. *Lampides boeticus*											R									
27. *Zizula hylax*	V	V																		
28. *Zizina otis*	V	U	U	U	C	V			U	U	U	U								C
29. *Euchrysops cnejus*	V	C	U	U			V													
Species per site	**13**	**11**	**10**	**12**	**9**	**9**	**6**	**8**	**12**	**12**	**17**	**11**	**8**	**11**	**6**	**8**	**8**	**8**	**9**	**8**

Results

Of the 29 butterfly species recorded for the island, the authors captured or positively sighted 23 during the period 7-18 March 2017 (Table 1). All vegetation communities mentioned earlier that were intersected by roads and tracks were surveyed. Abundance values for each species at each site are given in Table 3. The majority of species recorded during the visit were common to very common, at least at some sites. Six species previously recorded from Christmas Island were not sighted during our visit, viz. *Papilio demoleus malayanus* (Wallace, 1865), *Appias paulina micromalayana* (Fruhstorfer, 1910) *Melanitis leda* (Linnaeus, 1758), *Hypolimnas misippus* (Linnaeus, 1764), *Catochrysops panormus exiguus* (Distant, 1886) and *Prosotas aluta* (Druce, 1873).

There is some doubt about the identity and occurrence of *P. aluta* because authentic specimens cannot be located and none has been reported since 1947 (Moulds and Lachlan 1987). Also, *M. leda* had not been taken on the island since A. G. Butler recorded a single female in 1900 (Moulds and Lachlan 1987) until D. J. Phillips collected four specimens in 1989 (Parks Australia specimen labelled: 'D. J. Phillips 1989 (11/2), settlement'). There have been no positive sightings of *M. leda* since. *Euploea corinna* (W.S. Macleay, 1826) and *Catopsilia pomona* (Fabricius, 1775) were positively sighted by us, but not collected.

Species accounts

Family HESPERIIDAE

1. Badamia exclamationis (Fabricius, 1775) ranges from India and China to the Philippines, Indonesia, New Guinea and adjacent islands, northern Australia, Solomon Islands, New Caledonia and Fiji (Common and Waterhouse 1981, Braby 2000). Ian Knight collected the first specimen in Jan-Feb 2003 (I. Knight pers. comm.). In March 2017, adults (Figs 4-5) were uncommon across the island. Larvae were abundant on *Terminalia catappa* L. (Combretaceae) on the strand within the town area and on the lower terrace from Lily Beach to Ethel Beach on the NE side of the island. Larvae curled the edge of the leaf as shelters and later pupated within them (Fig. 13). Specimens showed little variation from Australian specimens other than a generally darker underside

2. *Hasora chromus* (Cramer, 1780) occurs widely from India, China and Taiwan, through Indonesia, to New Guinea and adjacent islands, northern Australia, Vanuatu and New Caledonia (Braby 2000). Ian Knight collected the first specimen in Jan-Feb 2003 (I. Knight pers. comm.). In March 2017, adults were seen flying around *Millettia pinnata* (L.) Panigrahi (Fabaceae) at Margaret Knoll. Larvae were numerous on seedlings of *M. pinnata* in the Parks Australia plant nursery, where they were considered a nuisance. Adults (Figs 6-9) reared in captivity were similar to Australian specimens except the underside was considerably darker than in those from eastern Australia.

Figs 4-12. Hesperiidae of Christmas Island: (4-5) *Badamia exclamationis*, (4) male (ws, 45), (5) female (ws, 53); (6-9) *Hasora chromus*, (6-7) males (ws, 40), (8-9) females (ws, 38); (10-13) *Borbo cinnara*, (10-11) males (ws, 27-28), (12) female (ws, 28). (ws = wingspan between forewing apices in mm).

3. *Borbo cinnara* (Wallace, 1866) ranges widely from India and southern China, through SE Asia, to New Guinea and adjacent islands, northern Australia, Solomon Islands, Vanuatu and New Caledonia (Common and Waterhouse 1981). Ian Knight collected the first specimen in Jan-Feb 2003 (I. Knight pers. comm.). Adults (Figs 10-12) were common along rainforest tracks, including the Margaret Knoll Track, Pink House Track, North-South Baseline, Murray Road, Blowholes Track and The Dales. Males patrolled the tracks and females were observed laying eggs on common weedy grasses, including Johnson River grass (*Paspalum conjugatum* Bergius), Crow's Foot grass (*Eleusine indica* (L.) Gaertn.) and Crabgrass (*Digitaria sanguinalis* (L.) Scop.). Larvae were frequently observed on their leaves. Mature larvae and pupae were fully exposed on the upper surface of the narrow leaves of *E. indica* (Figs 14-15), with an occasional cross-band of silk as incipient shelter formation. Larvae on broader-leaved *P. conjugatum* and *D. sanguinalis* constructed tubular shelters.

Family PAPILIONIDAE

4. Papilio memnon memnon Linnaeus, 1758 ranges from Java, Bawean, Natuna, Bangka, Borneo, Bali in Indonesia and Mapun, Sanga Sanga Islands off the coast of Borneo in the Philippines to Christmas Island (*http://www.nic.funet.fi/pub/sci/bio/life/insecta/lepidoptera/ditrysia/papilionoidea/*

Figs 13-21. Immature stages of Christmas Island butterflies: (13) pupa of *Badamia exclamationis* on a *Terminalia catappa* leaf; (14-15) larva and pupa of *Borbo cinnara*, (14) mature larva on *Eleusine indica* (L.) Gaertn., (15) pupa on Crow's Foot grass; (16-20) egg, larva and pupa of *Papilio memnon memnon*, (16) egg, (17) first instar larva, (18) final instar larva, (19) pupa, dorsal view, (20) pupa, lateral view; (21) egg of *Euchrysops cnejus cnejus* from Christmas Island on flower bud of food plant *Macroptilium atropurpureum.*

papilionidae/papilioninae/papilio/index.html). It was first taken on Christmas Island in November 1999 (Moulds and Humphrey 2000). The subspecific status of Christmas Island specimens was uncertain (Braby 2000) but examination of additional specimens shows that morphology and variability correspond to Rothschild's (1895) description of *P. m. memnon*.

Figs 22-24. Papilionidae of Christmas Island: (22-24) *Papilio memnon memnon*, (22) male (ws, 104), (23-24) females (ws, 104-127). (ws = wingspan between forewing apices in mm).

Adults (Figs 22-24) were common across the island, particularly where citrus was introduced in urban areas and along roadsides in rainforest, including at the Pink House, Pink House Track and Grants Well. Males outnumbered females approximately 20:1 and showed little variation. Females were polymorphic, with wide variation ranging from dark colours similar to the male through to extensive grey and white patches on both wings. The life history was not recorded for Christmas Island but immature stages (Figs 16-20) were common on citrus and correspond to those described for SE Asia by Tan and Khoon (2012).

Family PIERIDAE

6. *Appias olferna* Swinhoe, 1890 occurs from India, Myanmar, Laos and Vietnam to West Malaysia, Singapore, Sumatra, Java and Christmas Island (*http://yutaka.it-n.jp/pie/20220001.html*). Lambkin and Knight (2004) first recorded *A. olferna* on Christmas Island in 2003 and its life history was recorded there by Wilson and Johnson (2017).

Appias olferna (Figs 25-28) was very common throughout the island. While males and females were widely dispersed, females were more abundant where the food plant grew, particularly adjacent to the Airport, on Golf Course Road near the cemetery, the Pink House and on the Greta Beach Road. Immature stages were common in these situations.

8. *Catopsilia pomona* (Fabricius, 1775) is distributed from SE Asia, Indonesia, Christmas and Cocos-Keeling Islands to New Guinea and adjacent islands and Australia (Braby 2000). It was first recorded from Christmas Island in 1985 (Moulds and Lachlan 1987). Specimens were not collected but there were several confirmed sightings of adults flying through the rainforest over several days in the area near the Pink House in the centre of the island. Although the introduced *Cassia fistula* L. (Caesalpiniaceae) is recorded as a food plant (Braby 2000) and occurred in the urban areas on Christmas I., immature stages were not observed on it.

9. *Eurema blanda blanda* Boisduval, 1836 is distributed from West Malaysia to Borneo, Sumatra, Java and Christmas Island (Braby 2000), while *E. blanda saraha* (Fruhstorfer, 1912) is recorded in Australian territory from Dauan and Darnley Islands in Torres Strait (Braby 2000, Wilson and Johnson 2016). It was first recorded on Christmas Island in 1985 (Moulds and Lachlan 1987) and its life cycle there was described by Wilson and Johnson (2017). Adults (Figs 29-32) were very common throughout the island but particularly where the larval food plant occurred on Golf Course Road and at Greta Beach, on the lower terraces of the northern and eastern sides of the island respectively. Adults often occurred in groups of 20 or more at roadside water soaks, especially in the region of 'The Grotto' and the Christmas Island Resort in the NE of the island.

10. *Eurema alitha amplexa* (Butler, 1887) is endemic to Christmas Island and was first recorded at Flying Fish Cove in 1887 (Butler 1888) as *E. hecabe amplexa*. Moulds and Lachlan (1987) raised the subspecies to full species status based on the male genitalia. However, Yata (1995), in a revision of *Eurema* Hübner, concluded that *amplexa* should be treated as a subspecies of *E. alitha* (C. & R. Felder, 1862). The male genitalia and the shape and size of the sex scales on vein CuA on the underside of the male forewing are very similar to those of other subspecies of *E. alitha*. The dark margin of the upper forewing in the male is very narrow and not strongly indented between veins M_3 to CuA_2 compared with all other *E. alitha* subspecies.

Figs 25-36. Pieridae of Christmas I: (25-28) *Appias olferna*, (25-26) males (ws, 45-43), (27-28) females (ws, 45-47); (29-32) *Eurema blanda blanda*, (29-30) males (ws, 41-39), (31-32) females (ws, 42); (33-36) *Eurema alitha amplexa*, (33-34) males (ws, 34-30), (35-36) females (ws, 35). (ws = wingspan between forewing apices in mm).

Eurema alitha amplexa (Figs 33-36) occurred in all vegetation communities over the whole island, from the lower terraces to the central plateau. It was generally common and locally very common, particularly around 'The Grotto' region on the NE side of the island, where adults intermingled with the more abundant *E. blanda blanda*. The life history is not recorded.

Family NYMPHALIDAE

11. *Charaxes andrewsi* (Butler, 1900) is endemic to Christmas Island and was first recorded in 1897 (Butler 1900). It was rarely encountered in March 2017, with two captures (Figs 37-38) and 12 sightings. All were in rainforest

situations, where they patrolled along road corridors at Margaret Knoll, North-South Baseline and the Pink House. Adults were readily attracted to fruit baits. Larvae were recorded by Parks Australia staff on the food plant *Celtis timorensis* Span. (Cannabaceae) in the Parks Australia plant nursery in January 2016 (ANIC specimen label: 'J. Turl *et al*. emg. 28 Jan 2016'). A.N. Gillison also reared *C. andrewsi* on *Celtis* sp. (ANIC specimen label - no date) (Michael Braby pers. comm.). This plant occurs across the island in rainforests from the lower terraces to the central plateau (Claussen 2005), with many trees reaching 30 m in height. The specimen recorded from Roebourne, Western Australia in August 1899 (Braby 2016) was almost certainly a vagrant from Christmas Island.

12. *Euploea climena macleari* Butler, 1887 is only known from Christmas Island and the NW mainland of Australia, where it is reported to favour damp shady habitats (Braby 2000). The species was first recorded at Flying Fish Cove on Christmas Island in 1887 (Butler 1888). Moulds and Lachlan (1987) recorded it in January, March and from July to November. The immature stages and larval food plant (*Hoya*) were described from Christmas Island by Wilson and Johnson (2017). Specimens recorded at Roebourne and Derby in Australia (Braby 2016) are presumably vagrants from Christmas Island, as *Hoya* has not been recorded form these areas (Wilson and Johnson 2017). Therefore, its viable breeding population is probably restricted to Christmas Island.

Euploea climena macleari (Figs 39-40) males were widespread on the island and often seen feeding at flowering plants, particularly at Octopus Bush (*Heliotropium foertherianum* Diane & Hilger (formerly *Argusia argentea* (L. f.) Heine, Boraginaceae) in the car park at the airport and in the urban areas at Flying Fish Cove. Females were restricted to the undisturbed rainforests where the larval food plant occurred, particularly at The Dales, Pink House and Pink House Track, rarely flying through open or disturbed areas.

13. *Euploea corinna* (W.S. Macleay, 1826) occurs on the Cocos-Keeling and Christmas Islands, Bali, Lombok, Kisar, Torres Strait islands, Australia and Lord Howe and Norfolk Islands (Braby 2000). The only adult sighted in March 2017 was in the urban area at the Parks Australia office. Known food plants of *Ficus* species and Oleander (*Nerium oleander* L.) were common in the rainforests throughout the island and in urban areas respectively, but immature stages were not observed.

14. *Hypolimnas anomala anomala* (Wallace, 1869) occurs from southern Thailand, West Malaysia, Singapore and the Philippines, through Indonesia to Bali and Christmas Island (*https://en.wikipedia.org/wiki/Hypolimnas_anomala*). It was first reported on Christmas Island in 1932 by Pendlebury (1933) and Moulds and Lachlan (1987) recorded it in all months, being very plentiful in January. The life history was recorded from Christmas Island by Wilson and Johnson (2017).

Adults (Figs 41-42) occurred over the whole island in all vegetation communities from the lower terraces to the central plateau and it was one of the few species that frequented disturbed areas. Males were very common, being the predominant butterfly seen on the island, while females were rarely encountered. Immature stages were similarly very common, larvae often defoliating the food plant. Females were often seen 'guarding' their egg masses, a practice demonstrated to increase survival rates of eggs and first instar larvae by reducing predation and parasites (Nafus and Schreiner 1988).

15. *Hypolimnas bolina nerina* (Fabricius, 1775) occurs on Cocos-Keeling and Christmas Islands, Tanimbar Island, the Kai and Aru Islands, New Guinea, Torres Strait islands, Australia, the Bismarck Archipelago, Solomon Islands, Vanuatu, Lord Howe and Norfolk Islands and New Zealand (Braby 2000). It was first recorded at Flying Fish Cove on Christmas Island in 1887 (Butler 1888).

Adults (Figs 43-44) were very common throughout the island in all vegetation communities as well as disturbed mined and urban areas. Males and females showed considerable size and pattern variation. Males varied in extent of the white patches on the wing uppersides; females showed extreme variability in extent of white patches, ground colour and in colour and extent of the subtornal patch. All variation is consistent with that seen in Australia. Immature stages were common on Blue Snake Weed (*Stachytarpheta cayennensis* (Rich) Vahl (Verbenaceae) growing along roads and tracks, particularly at the Pink House and on the Pink House Track.

17. *Danaus petilia* (Stoll, 1790) occurs on Cocos-Keeling and Christmas Islands, New Guinea, Torres Strait islands, Australia, Vanuatu, Lord Howe and Norfolk Islands and New Zealand (Braby 2000). It was first recorded on Christmas Island in 1897 (Butler 1900).

Specimens were uncommon at Flying Fish Cove and the airport on Octopus Bush (*Heliotropium foertherianum* Diane & Hilger, Boraginaceae), imbibing sap exudate on the leaves that resulted from feeding by larvae of the 'salt and pepper moth' (*Utetheisa lotrix* (Cramer, 1777) or *U. pulchelloides* Hampson, 1907, Erebidae). Two specimens were encountered at Grants Well and in a revegetated area on the East-West Baseline. Several specimens were also seen flying over the sea from the north-west towards the island. Specimens are generally larger and darker (Figs 45-46) than Australian specimens.

Figs 37-48. Nymphalidae of Christmas Island: (37-38) *Charaxes andrewsi*, (37) male (ws, 68), (38) female) (ws, 87); (39-40) *Euploea climena macleari*, (39) male (ws, 58), (40) female) (ws, 61); (41-42) *Hypolimnas anomala anomala*, (41) male (ws, 65), (42) female (ws, 75); (43-44) *Hypolimnas bolina nerina*, (43) male (ws, 60), (44) female (ws, 67); (45-46) *Danaus petilia*, (45) male (ws, 65), (46) female (ws, 65); (47-48) *Junonia villida calybe*, males (ws, 38-41). (ws = wingspan between forewing apices in mm).

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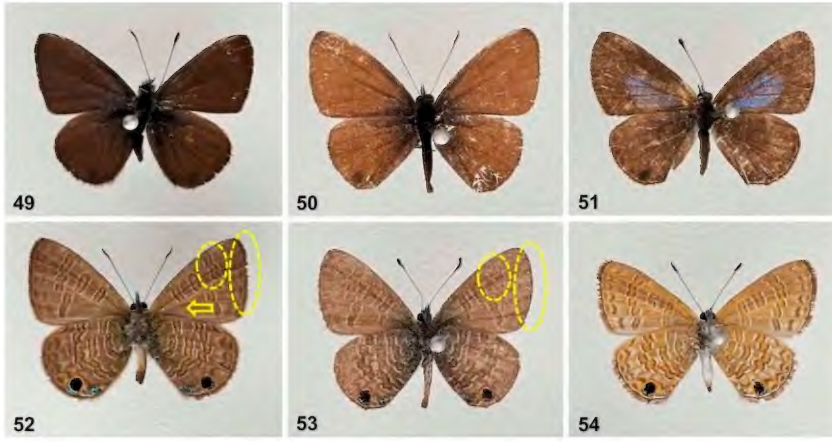
18. *Junonia villida calybe* (Godart, 1819) occurs on Cocos-Keeling and Christmas Islands, New Guinea and adjacent islands, Torres Strait islands, Australia, Lord Howe and Norfolk Islands, New Zealand and many of the islands of the south-west Pacific (Braby 2000). It was first recorded on Christmas Island in 1897 (Butler 1900). Adults were very common in all situations, particularly in disturbed areas along roads and tracks, mined areas and urban areas, often resting on bare ground. Adults (Figs 47-48) showed little variation form Australian specimens.

Family LYCAENIDAE

21. *Prosotas dubiosa lumpura Corbet, 1938* ranges from Thailand and West Malaysia to Christmas Island (*http://yutaka.it-n.jp/lyc4/81350020.html*). Adults (Figs 49-54) were uncommon, but were more frequently encountered in rainforest, particularly where flowering *Millettia pinnata* (L.) Panigrahi occurred at Margaret Knoll. This was recorded as a larval food plant for *P. d. dubiosa* (Semper, 1879) in Australia by Braby (2016). Adults showed great variation in wingspan (17-21 mm), underwing ground colour from dark brown to beige, curvature of the forewing termen and male wing uppersides ranging from brown to dark purple. Arrangement of the wing bands also varies considerably, with the postmedial band on the forewing ranging from straight to distinctly curved and the lower submedian band ranging from distinct to absent (Figs 49-54). The arrangement of spots on the lower part of the forewing postmedial band of the female also differs considerably from that of the male.



Figs 49-54. Adults of *Prosotas dubiosa lumpura* from Christmas Island with highlighted variations in wing curvature and markings: (49-50) males (ws, 20-17), (51) female (ws, 18), (52-53) male (ws, 21-18), (54) female (ws, 18). (ws = wingspan between forewing apices in mm).

22. *Petrelaea tombugensis* (Röber, 1886) occurs from the Andaman Islands, Sulawesi and Maluku, through New Guinea, Torres Strait islands and northern mainland Australia to New Britain and the Solomon Islands (Fujioka and Chiba 1988, Braby 2000). Ian Knight (pers. comm.) first collected it on the island in 2003 at a similar location and situation to those recorded below. Genitalia of Knight's specimens were examined by Trevor Lambkin (pers. comm.), who determined them to be *P. tombugensis* and not the closely related *Petrelaea dana* (de Nicéville, 1883). The two species are broadly sympatric throughout the region and are indistinguishable on wing pattern (Fujioka and Chiba 1988, Parsons 1999). A birding group in 2011 (Frank Pierce pers. comm.) photographed *P. tombugensis* adults on *Terminalia catappa* L. (Combretaceae) on the strand within the town urban area. This is a recorded larval food plant (Braby 2000). Adult butterflies (Figs 55-56) were rare in March 2017, with only two specimens collected at mud-soaks on a rainforest track near the Pink House (Site 11).

23. *Nacaduba kurava nemana* Fruhstorfer, 1916 is known from Thailand, West Malaysia, Singapore, Borneo, Sumatra and Enggano Island south of Sumatra (*http://yutaka.it-n.jp/lyc4/81240020.html*) and was first recorded on Christmas Island in 1985 (Moulds and Lachlan 1987). Adults (Figs 57-59) were rarely encountered and then only in rainforest near the Pink House on the central plateau. Male and female undersides have no white medial band and the female has no white central area on the upperside. This subspecies is particularly striking, with significant variation from the two Australian subspecies *N. k. parma* Waterhouse & Lyell, 1914 and *N. k. felsina* Waterhouse & Lyell, 1914.

24. *Jamides bochus* Stoll, 1782 ranges from India, Sri Lanka, Thailand, eastern China, Taiwan, Hong Kong, Philippines and West Malaysia, through parts of Indonesia to New Guinea (Braby 2000, Parsons 1999). Christmas Island is the only locality on Australian territory known for this species and the subspecific status of the population is uncertain. It was first recorded on Christmas Island in 1975 (Moulds and Lachlan 1987). The life history on *Canavalia cathartica* Thouars (Fabaceae) was recorded from Christmas Island by Wilson and Johnson (2017). Adults (Figs 60-63) were common across the island, including at Margaret Knoll, South Point and the Pink House, but particularly where the food plant occurred along Golf Course Road at 'The Grotto'. Yellow crazy ants were seen attending the larvae of *J. bochus*, presumably collecting exudate from nectary organs, but there was no evidence of predation.

26. *Lampides boeticus* (Linnaeus, 1767) ranges from western Europe and Africa, through SE Asia, to Christmas Island, Australia, islands of the western Pacific and as far east as Hawaii (Braby 2000). It was first recorded on Christmas Island in 1975 (Moulds and Lachlan 1987). Only one specimen (Fig. 64) was collected, along a rainforest track near the Pink House.

Figs 55-76. Lycaenidae of Christmas Island: (55-56) *Petrelaea tombugensis*, (55) male (ws, 22), (56) female (ws, 21); (57-59) *Nacaduba kurava nemana*, (57-58) males (ws, 23-22), (59) female (ws, 23); (60-63) *Jamides bochus*, (60-61) males (ws, 23), (62-63) females (ws, 27-22); (64) *Lampides boeticus*, male (ws, 24); (65-68) *Zizula hylax*, (65-66) males (ws, 17), (67-68) females (ws, 16-17); (69-72) *Zizina otis*, (69-70) males (ws, 20-18), (71-72) females (ws, 19-21); (73-76) *Euchrysops cnejus cnejus*, (73-74) males (ws, 24-25), (75-76) females (ws, 26). (ws = wingspan between forewing apices in mm).

27. *Zizula hylax* (Fabricius, 1775) ranges widely in the Afrotropical, Oriental and Australian Regions, extending to the Solomon Islands and Vanuatu (Braby 2000). It was first reported on Christmas Island in 1932 by

Pendlebury (1933). The subspecific status of the population is uncertain. Christmas Island specimens differ from the Australian mainland subspecies *Z. h. attenuata* (T.P. Lucas, 1890) in their slightly larger wingspan (males and females 16-17 mm), dark blue and broader black margin on the male upperside, the brown to extensive blue sulphuring on the female upperside and the paler grey underside with distinct black spots. Adults (Figs 65-68) were very common, particularly where the larval food plant *Ruellia prostrata* Poir. (Acanthaceae) was abundant in the north of the island, especially along the roadside and other disturbed areas on Golf Course Road. *Ruellia* is recorded as a larval food plant in Australia (Braby 2000).

28. *Zizina otis* (Fabricius, 1787) was first recorded on Christmas Island in 1985 (Moulds and Lachlan 1987). Its subspecies status is not resolved. The Australian *Z. labradus* (Godart, 1824) and the Oriental *Z. otis* have been treated as full species separated by differences in male genitalia (Common and Waterhouse 1981). Braby (2000) listed the range of *Z. labradus* as from Christmas Island and Australia to Lord Howe and Norfolk Islands and New Zealand, but later listed the Christmas Island population as *Z. otis* (Braby 2004). A review of *Zizina* Chapman by Yago *et al*. (2008) regarded *Z. labradus* as a subspecies of *Z. otis* on the basis of molecular studies using mtDNA and slight genitalia differences that Yago *et al*. considered would allow viable interbreeding.

Christmas Island specimens (Figs 69-72) differ from the typical Australian *Z. o. labradus* in the dark blue on the male wing uppersides, the brown on the female wing uppersides, the darker grey to brown underside with distinct black spots, and the absence of the greyish-white postmedian band on the underside of both wings. Christmas Island specimens show little variation and are similar to *Z. o. otis* (Fabricius, 1787), which occurs from southern China, Myanmar, Laos, Thailand, Malaysia, Philippines to Indonesia (Yago *et al*. 2008). Adults were uncommon throughout the undisturbed forests but very common in the township around lawns infested with Creeping Tick Trefoil (*Desmodium triflorum* (L.) DC., Fabaceae), a small, prostrate and strongly branched legume with mauve flowers common in lawns and mown areas. The authors have previously reared *Z. o. labradus* on this plant from northern Queensland.

29. *Euchrysops cnejus cnejus* (Fabricius, 1798) ranges from India through Myanmar and Southern Thailand to Malaysia and Indonesia (*https://en.wikipedia.org/wiki/Euchrysops_cnejus*). It was first collected on Christmas Island by Ian Knight in 2003 (I. Knight, pers. comm.) and later recorded there by Williams and Algar (2006) on specimens collected in 2004. Adults (Figs 73-76) were very common where the larval food plant Siratro (*Macroptilium atropurpureum* (DC.) Urb.), Fabaceae) occurred in all urban and mined areas such as on Lily Beach Road, but were uncommon elsewhere. Siratro has become a weed of disturbed areas, particularly in urban and old mined areas.

Eggs were observed being laid on flower buds (Fig. 21) and larvae were attended by one or two yellow crazy ants, presumably collecting nectary organs exudates, but there was no evidence of predation.

Discussion

The tracks through the rainforest that covers most of the island contained the greatest diversity of species, while the unrehabilitated mined areas were almost devoid of butterflies with the exceptions of *Hypolimnas bolina nerina* and *Junonia villida calybe*. Many species, including *Papilio memnon memnon*, *Appias olferna*, *Hypolimnas bolina nerina*, *Zizula hylax*, *Zizina otis* and *Euchrysops cnejus cnejus*, were common to very common along road corridors and tracks in the rainforest and throughout the urban areas where their respective weed food plants occurred. It is notable that whereas Moulds and Lachlan (1987) recorded no Hesperiidae after intensive collecting in 1985 and survey of other collections, three species were collected by Ian Knight in 2003, all of which were still present during our 2017 survey. The three species, *Badamia exclamationis*, *Borbo cinnara* and *Hasora chromus,* were all common, especially immature stages on their respective food plants. Also interesting are the recent records of other common/very common species that were not recorded in 1985, such as *Papilio memnon memnon*, *Appias olferna*, *Eurema blanda blanda*, *Euchrysops cnejus cnejus* and *Zizina otis,* suggesting that these species are recent introductions through natural migration, possibly following establishment of their non-native food plants on the island and perhaps transport of eggs or larvae by human agency.

One of our objectives was to note any effects of the yellow crazy ant on butterfly populations. The disastrous effects this ant has had on the endemic red crabs (*Gecarcoidea natalis* Pocock, 1888) of the island is well known (O'Dowd et al. 2003), but little is known of the risk posed to butterflies. In its 'super-colony' state (Thomas et al. 2010), the yellow crazy ant is indiscriminately destructive and has caused a rapid, catastrophic shift in the rainforest ecosystem, with dramatic effects on the endemic red crab population and other forest dynamics where 'super colonies' of ants have formed. However, we found that in low density 'normal' population numbers, yellow crazy ants showed no aggression toward any butterfly immature stages that we observed. For example, many citrus trees infested with scale insects had a large population of ants but *Papilio memnon* eggs and larvae on the same trees appeared unaffected. Dead butterfly larval remains (presumably from parasites) were also ignored by ants in these situations. An even more surprising finding was that of yellow crazy ants actively attending larvae of *Jamides bochus* and *E. cnejus*.

Parks Australia is taking action to stop the formation of 'super-colonies' through baiting and research, as well as the planned introduction of an encyrtid scale parasite (*Tachardiaephagus somervillei* (Mahdihassan, 1923)) to reduce the ants' main food source (Parks Australia pers. comm.).

Eradication of the ant from the island will be impossible, but our observations suggest that the butterflies collected in March 2017 are not being adversely affected by the presence of the ant at 'normal' population density.

The butterfly population within the National Park contained the greatest diversity of species and numbers observed on the island. The National Park is well managed even though weed spread along road corridors and along tracks is largely uncontrolled. For example, the *Appias olferna* food plant, *Cleome rutidosperma* DC. (Capparaceae) (Fringed spiderflower), appears to be spread by mowing along road corridors and by road maintenance in the National Park. Other butterfly weed food plants also appear to be spread along roads and tracks. Outside the National Park, mining poses a significant threat through habitat destruction. Unrehabilitated mining areas were weed infested with minimal regrowth of natural flora. Even sensitive areas actively rehabilitated by Parks Australia showed no evidence of butterfly immature stages on the planted species other than abundant larvae of *Hypolimnas anomala anomala* on the replanted larval food plant *Pipturus argenteus* var. *lanosus* (Skottsb.) (Urticaceae). However, the areas assessed were relatively recently replanted and further assessment in future might show positive results.

Acknowledgements

We thank Parks Australia and Department of Environment & Energy who made our research possible. A special thanks to Samantha Flakus, Dion Maple and Chrisafina Rick (Parks Australia) and Justin Keast (Dept of Environment) and Chiew Yee Lim (Dept of Infrastructure & Regional Development) for assistance in provision of permits. On Christmas Island, the staff of Parks Australia, led by Scott Suridge and Graeme Beech, were of great assistance. Particular mention goes to Alasdair Grigg and Trent Lane for assistance with plant identification and distribution and to Caitlyn Pink for access to Parks Australia specimens and equipment and advice on local butterfly distribution. Caitlyn has been particularly helpful with our research since our visit. Thanks to Ian Knight and Frank Pierce for information on their observations of Christmas Island butterflies and special thanks to Michael Braby for checking variability of *Prosotas dubiosa lumpura* in the Australian National Insect Collection (ANIC) and providing comment. Trevor Lambkin permitted citation of his identification of *Petrelaea tombugensis*. Thanks also to Frank Tomlinson and David Merefield for specimen photography. Geoff Monteith prepared Fig. 1 using the Atlas of Living Australia mapping tool and gave much editorial help.

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A REVIEW OF THE SUBGENERA *ASIADACUS* PERKINS, *DIPLODACUS* MAY, *HEMIGYMNODACUS* HARDY, *NIUGINIDACUS* DREW, *PAPUODACUS* DREW AND *SINODACUS* ZIA OF *BACTROCERA* MACQUART (DIPTERA: TEPHRITIDAE: DACINAE)

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Abstract

The *Bactrocera* Macquart subgenera *Asiadacus* Perkins, *Diplodacus* May, *Niuginidacus* Drew, *Papuodacus* Drew and *Sinodacus* Zia (= *Pacifodacus* Drew) are reviewed and 23 species included. *Hemigymnodacus* Hardy is placed as a **new synonym** of subgenus *Zeugodacus* Hendel, with *B.* (*Z.*) *diversa* (Coquillett) and *B.* (*Z.*) *mukiae* Drew & Romig newly transferred. Eleven additional species currently included in *Asiadacus*, *Papuodacus* or *Sinodacus* are also transferred to subgenus *Zeugodacus*: *B.* (*Z.*) *apiciflava* Yu, He & Chen, *B.* (*Z.*) *careomacula* Drew & Romig, *B.* (*Z.*) *maculifacies* (Hardy) (= *B.* (*Z.*) *hengsawadae* Drew & Romig, 2013, **syn. n.**), *B.* (*Z.*) *melanopsis* (Hardy) [all ex *Asiadacus*], *B.* (*Z.*) *complicata* White, *B.* (*Z.*) *fereuncinata* Drew & Romig, *B.* (*Z.*) *maculifemur* (Hering), *B.* (*Z.*) *ochrosterna* Drew & Romig and *B.* (*Z.*) *sinensis* Yu, Bai & Chen [all ex *Papuodacus*] and *B.* (*Z.*) *bogorensis* (Hardy) and *B.* (*Z.*) *hamaceki* Drew & Romig (both ex *Sinodacus*). Host plants, where known, are the fruit or flowers of Cucurbitaceae. A key to the 18 recorded species of *Sinodacus* is included and the early phylogenetic history of the four groups of subgenera within *Bactrocera* is discussed. The suggestion that Cucurbitaceae represent the ancestral host plants for both *Dacus* Fabricius and *Zeugodacus* is rejected.

Introduction

This paper reviews the Indo-Australian subgenera *Asiadacus* Perkins, *Diplodacus* May, *Hemigymnodacus* Hardy, *Niuginidacus* Drew, *Papuodacus* Drew and *Sinodacus* Zia (= *Pacifodacus* Drew) of *Bactrocera* Macquart, all belonging in the *Zeugodacus* group of subgenera as defined by Drew (1989). The two *Hemigymnodacus* species and eleven additional species included in *Asiadacus, Papuodacus* or *Sinodacus* by Drew and Romig (2013, 2016) are transferred to subgenus *Zeugodacus* Hendel. *Bactrocera* (*Sinodacus*) *fuscans* (Wang), previously discussed by Hancock and Drew (2018), is transferred from *Asiadacus* Perkins.

Supraspecific nomenclature

All species included here were placed in genus *Zeugodacus* by Doorenweerd *et al.* (2018), largely on the basis of molecular studies by Virgilio *et al.* (2015) and San Jose *et al.* (2018). However, we continue to include them in a group of subgenera within genus *Bactrocera*, since morphological characters used to support the proposed generic association with *Dacus* Fabricius (scutum with medial vitta and either presutural extensions of the lateral postsutural vittae or an isolated presutural vitta connected with the notopleural lobe) are likely to be homoplasious or plesiomorphic: they also occur in subgenera *Tetradacus* Miyake, *Hemizeugodacus* Hardy and *Notodacus* Perkins, a medial vitta occurs in *Apodacus* Perkins and some *Bulladacus* Drew & Hancock and presutural extensions of the lateral vittae

occur sporadically within subgenera *Bactrocera*, *Bulladacus* and *Calodacus* Hancock. We regard the frequent presence of secondary basal scutellar and/or prescutellar acrostichal setae in both *Bactrocera* and *Zeugodacus* (Hancock and Drew 2018) [this also applies to the infrequent appearance of secondary postpronotal setae] as a more reliable synapomorphy, since these setae are not known in *Dacus*, *Monacrostichus* Bezzi or *Ichneumonopsis* Hardy. The presumed synapomorphy of Cucurbitaceae as an ancestral host plant for *Dacus* and *Zeugodacus* (*e.g.* White 2006) is discussed below.

Genus *Bactrocera* Macquart

Subgenus *Asiadacus* Perkins

Asiadacus Perkins, 1937: 57. Type species *Chaetodacus bakeri* Bezzi, 1919, by original designation.

Definition. Abdominal sternite V of male with a slight posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male present; postpronotal setae absent; supra-alar setae absent; prescutellar acrostichal setae absent; one pair of scutellar setae; scutum with postsutural medial and lateral yellow vittae present and lateral yellow triangles that reach the notopleural lobes; wing with a large, oval apical spot that reaches but does not cross vein M; abdomen oval with tergite I not quadrate.

Response to male lures. Cue lure or unknown.

Included species. *Bactrocera* (*A.*) *apicalis* (de Meijere) and *B.* (*A.*) *bakeri* (Bezzi).

Host plants. Flowers of Cucurbitaceae.

Comments. Although most species previously included in *Asiadacus* belong elsewhere (see below), we continue to recognise it as a separate subgenus until the relationships of its two remaining species are better known.

For detailed morphological descriptions and illustrations see Drew and Romig (2013) and for an illustrated key to these and previously included specis see Drew and Romig (2016).

B. (*Asiadacus*) *apicalis* (de Meijere)

Dacus apicalis de Meijere, 1911: 376. Type locality Sindanglaja, Java, Indonesia.

Dacus (*Asiadacus*) *modicus* Hardy, 1973: 17. Type locality Nakhon Sawan, Thailand. Syn. Drew and Romig 2013: 30.

Dacus (*Asiadacus*) *dianensis* Wang & Zhao, 1989: 215. Type locality Yiwubanna, Yunnan, China. Syn. Drew and Romig 2013: 30.

Dacus (*Asiadacus*) *nadanus* Chao & Lin, 1993: 139. Type locality Da Xian, Nada, Hainan, China. Syn. Drew and Romig 2013: 30.

Bactrocera (*Asiadacus*) *apicalis* (de Meijere); Norrbom *et al*. 1997: 87; Drew and Romig 2013: 30.

Distribution. China (Yunnan, Hainan), Vietnam, Thailand, Malaysia (West, Sarawak, Sabah), Brunei, Indonesia (Java, Kalimantan, Sulawesi) (Drew and Romig 2013).

Host plant. Flowers of *Trichosanthes wawraei* (Cucurbitaceae) (Allwood *et al.* 1999).

Male lure. Cue lure.

Comments. This species differs from *B. bakeri* in having a gap between the costal band and apical spot, lateral postsutural vittae usually ending before the intra-alar setae and a weaker supernumerary lobe on the male wing. However, at least some specimens from Sabah are intermediate, having the apical spot extending narrowly along the costa mid-way across the gap, the lateral postsutural vittae ending beyond the intra-alar setae and a slightly better developed supernumerary lobe, suggesting that the two taxa are conspecific.

B. (*Asiadacus*) *bakeri* (Bezzi)

Chaetodacus bakeri Bezzi, 1919: 426. Type locality Davao, Mindanao, Philippines.

Bctrocera (*Asiadacus*) *bakeri (*Bezzi); Norrbom *et al*. 1999: 87; Drew and Romig 2013: 33.

Distribution. Philippines (Mindanao).

Host plant. None recorded.

Male lure. None recorded.

Comments. As noted above, this species is possibly conspecific with *B. apicalis*, differing only in having the costal band and apical spot weakly united along the costa and a more strongly developed supernumerary lobe on the male wing.

Excluded species

Bactrocera absoluta (Walker) was transferred from *Asiadacus* to subgenus *Parasinodacus* Drew & Romig by Hancock and Drew (2017c) and *B. fuscans* (Wang) is transferred to *Sinodacus* Zia in this study. Four additional species included by Drew and Romig (2013) in *Asiadacus* are transferred to subgenus *Zeugodacus* below. For detailed morphological descriptions and illustrations of them see Drew and Romig (2013) and for an illustrated key to species see Drew and Romig (2016). Males of all four species respond to cue lure.

Bactrocera (*Z.*) *apiciflava* Yu, He & Chen, 2011, originally described in subgenus *Javadacus* Hardy from Yunnan, China (Yu *et al.* 2011), was referred to *Asiadacus* and recorded from northern Thailand by Drew and Romig (2013). Morphologically, it appears to belong in the *B.* (*Z.*) *scutellaris* complex of Drew and Romig (2013), differing from other species in the homoplasious loss of both supra-alar and prescutellar acrostichal setae.

Bactrocera (*Z.*) *careomacula* Drew & Romig, 2013 is known only from Mt Makiling, Luzon, Philippines (Drew and Romig 2013). It appears to be related closely to *B.* (*Z.*) *melanopsis* (Hardy) from Sulawesi, both species having crossvein DM-Cu infuscated and extensively black femora, both common characters in subgenus *Zeugodacus*.

Bactrocera (*Z.*) *maculifacies* (Hardy, 1973) was recorded from Thailand and southern Vietnam by Drew and Romig (2013). Its host plant is the fruit of *Siphonodon celastrineus* (Celastraceae) (Allwood *et al.* 1999), this and its overall morphology (see Drew and Romig 2013) better placing it in subgenus *Zeugodacus*. *Bactrocera* (*Z.*) *hengsawadae* Drew & Romig, 2013, also bred from *Siphonodon* at the same localities and normally also with only 1 pair of scutellar setae but occasionally with 1 or 2 weak basal setae (Drew and Romig 2013), is here placed as a **new synonym** of *B.* (*Z.*) *maculifacies*. The presence or absence of supra-alar, prescutellar acrostichal and basal scutellar setae is thus infraspecifically variable in this species (as is also the case in *B.* (*Z.*) *cucurbitae* (Coquillett) – see White 1999). The record of *Ocimum* (Lamiaceae) as a host plant for *B. hengsawadae* by Drew and Romig (2013) is incorrect; the holotype was swept from *Ocimum* using a net likely contaminated by cue lure (DLH pers. obs.).

Bactrocera (*Z.*) *melanopsis* (Hardy, 1982) is known only from Sulawesi (Drew and Romig 2013). It is very similar to *B.* (*Z.*) *careomacula* from the Philippines (see above).

Subgenus *Diplodacus* May

Diplodacus May, 1951: 8. Type species *Dacus signatifer* Tryon, 1927, by original designation.

Definition. Abdominal sternite V of male with a slight posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male present; postpronotal setae absent; supra-alar setae absent; prescutellar acrostichal setae absent; one or two pairs of scutellar setae; scutum with postsutural medial and lateral yellow vittae present and lateral yellow triangles absent; wing with a very narrow costal band; abdomen oval with tergite I not quadrate.

Comments. Although *Diplodacus* is monotypic, we continue to recognise it on the basis of the character combination of both supra-alar and prescutellar acrostichal setae absent and pecten present, plus lack of attraction to known male lures and its Capparaceae host plants. In its lack of lure response and general appearance it closely resembles *Austrodacus* Perkins, differing in its apically acute rather than weakly trilobed aculeus and presence of the male pecten. We regard these two subgenera, both confined to the Australian Region, as sister groups.

Response to male lures. None recorded.

Included species. *Bactrocera* (*D.*) *signatifer* (Tryon).

Host plants. *Capparis* spp (Capparaceae).

B. (*Diplodacus*) *signatifer* (Tryon)

Dacus signatifer Tryon, 1927: 210. Type locality Bowen, Queensland.
Bactrocera (*Diplodacus*) *signatifera* (Tryon); Drew 1989: 186.

Distribution. Australia (coastal Northern Territory, Torres Strait islands and NE Queensland as far south as Bowen) (Hancock *et al*. 2000).

Host plants. Fruit of *Capparis lucida, Capparis sepiaria* and *Capparis* sp. (Capparaceae); a record from *Barringtonia calyptrata* (Barringtoniaceae) is a likely error (Hancock *et al.* 2000).

Male lure. Not attracted to any known lure (cue lure, methyl eugenol or zingerone).

Comments. The subgeneric characters, pale coloration, host plants and lack of lure response readily separate *B. signatifer* from all other Australian species of *Bactrocera*. For a detailed description and illustration see Drew (1989).

Subgenus *Hemigymnodacus* Hardy

Dacus (*Hemigymnodacus*) Hardy, 1973: 19. Type species *Dacus diversus* Coquillett, 1904, by original designation.

Definition. Abdominal sternite V of male with a slight posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male absent; postpronotal setae absent; supra-alar setae present; prescutellar acrostichal setae present or absent; one or two pairs of scutellar setae; scutum with postsutural medial and lateral yellow vittae present and lateral yellow triangles absent; wing with a narrow costal band; abdomen oval with tergite I not quadrate.

Comments. Only the lack of the male pecten separates the two included species, *B. diversa* (Coquillett) and *B. mukiae* Drew & Romig, from those in subgenus *Zeugodacus*. Their scutellar and pattern characteristics, together with their different host use type (flowers or fruit respectively), suggest that they are not closely related and the loss of the pecten, which occurs independently several times within genus *Bactrocera*, is evidently homoplasious. A molecular study by Krosch *et al*. (2012) placed *B. diversa* in a clade containing *B.* (*Z.*) *caudata* (Fabricius) [the type species of subgenus *Zeugodacus*], *B*. (*Z.*) *ishigakiensis* (Shiraki) and the *scutellaris* complex species *B*. (*Z.*) *atrifacies* (Perkins), *B*. (*Z.*) *diaphora* (Hendel) and *B*. (*Z.*) *scutellata* (Hendel), while a separate molecular study by San Jose *et al*. (2018) placed *B. diversa* and *B. mukiae* in separate clades within *Zeugodacus,* the latter alongside *B*. (*Z.*) *arisanica* (Shiraki), *B*. (*Z.*) *aithonata* Drew & Romig, *B*. ('*Javadacus*') *trilineata* (Hardy) and *B*. (*Z.*) *tappanus* (Shiraki). Hence, neither morphological nor molecular data support the

recognition of *Hemigymnodacus* as a separate subgenus and we regard it here as a **new synonym** of subgenus *Zeugodacus*.

B. (*Zeugodacus*) *diversa* (Coquillett)

Dacus diversus Coquillett, 1904: 139. Type localities Bangalore, India and Colombo, Sri Lanka.

Dacus quadrifidus Hendel, 1928: 139. Type locality Ceylon [Sri Lanka]. Syn. Norrbom *et al.* 1999: 99.

Dacus latifae Anwar Cheema, 1964: 302. Type locality Lyallpur, Pakistan. Syn. Drew and Romig 2013: 205.

Dacus citronellae Kapoor & Katiyar, 1969: 123. Type locality Pusa, Bihar, India. Syn. Norrbom *et al.* 1999: 99.

Bactrocera (*Hemigymnodacus*) *diversa* (Coquillett); Allwood *et al*. 1999: 19; Drew and Romig 2013: 205.

Distribution. China (Sichuan, Yunnan), Vietnam, Thailand, Bangladesh, India, Pakistan, Nepal, Sri Lanka (Drew and Romig 2013, Doorenweerd *et al.* 2018).

Host plants. Flowers of *Benincasa hispida, Coccinia grandis, Cucurbita maxima, Cucurbita pepo, Lagenaria siceraria, Luffa acutangula, Luffa aegyptiaca* and *Trichosanthes wawraei* (Cucurbitaceae) (Allwood *et al.* 1999). Not recorded from fruit.

Male lure. Weakly attracted to methyl eugenol.

Comments. The scutellum has I or (occasionally) 2 pairs of setae and prescutellar acrostichal setae are present. Sternite IV in males is large and very broadly rectangular. For a detailed description and illustration see Drew and Romig (2013).

B. (*Zeugodacus*) *mukiae* Drew & Romig

Bactrocera (*Hemigymnodacus*) *mukiae* Drew & Romig, 2013: 207. Type locality Doi Luong Nat. Park, Chiang Rai, Thailand.

Distribution. Northern Thailand and northern Vietnam (Drew and Romig 2013). Additional males recorded from Bhutan and northern Vietnam by Drew and Romig (2013) lack the scutellar spot and have the pecten present; these were excluded from the type series and likely belong to other, similar species in the *B.* (*Z.*) *scutellaris* complex.

Host plants. Fruit of *Zehneria wallichii* and *Z. maysorensis* (Cucurbitaceae) (Drew and Romig 2013).

Male lure. Uncertain. Records from cue lure (Drew and Romig 2013) refer to the additional males noted above.

Comments. The scutellum has 1 pair of setae and prescutellar acrostichal setae are present or absent. Sternite IV in males is small and quadrate. For a detailed description and illustration see Drew and Romig (2013).

Subgenus *Niuginidacus* Drew

Bactrocera (*Niuginidacus*) Drew, 1989: 15. Type species *Bactrocera singularis* Drew, 1989, by original designation.

Definition. Abdominal sternite V of male with a slight posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male absent; postpronotal setae absent; supra-alar setae present; prescutellar acrostichal setae absent; one pair of scutellar setae; scutum with a broad postsutural medial yellow vitta present, postsutural lateral yellow vittae absent and lateral yellow triangles absent; wing with a narrow costal band; abdomen elongate-oval.

Response to male lures. Cue lure.

Included species. *Bactrocera* (*N.*) *singularis* Drew.

Host plants. None known.

Comments. Although the sole included species is similar in overall appearance to eastern species of subgenus *Sinodacus* (see below), the lack of both pre- and postsutural lateral yellow vittae and the male pecten, together with its relatively elongate abdomen, make a possible sister taxon difficult to determine and we therefore retain subgenus *Niuginidacus* until its relationships are better understood.

B. (*Niuginidacus*) *singularis* Drew

Bactrocera (*Niuginidacus*) *singularis* Drew, 1989: 192. Type locality Kunai Creek, Mt Kaindi, Morobe Province, Papua New Guinea.

Distribution. Papua New Guinea (Morobe Province) (Drew 1989).

Host plant. None recorded.

Male lure. Cue lure.

Comments. For a detailed description and illustration see Drew (1989).

Subgenus *Papuodacus* Drew

Dacus (*Papuodacus*) Drew, 1972a: 13. Type species *Dacus pallescentis* Drew, 1971 (= *Bactrocera neopallescentis* Drew, 1989), by original designation.

Definition. Abdominal sternite V of male with a slight posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male present; postpronotal setae absent; supra-alar setae absent; prescutellar acrostichal setae present or absent; two pairs of scutellar setae; scutum with postsutural medial and lateral yellow vittae present and lateral yellow triangles absent; wing with a narrow costal band; abdomen oval with tergite I slightly petiolate but not quadrate.

Response to male lures. Cue lure.

Included species. *Bactrocera* (*P.*) *neopallescentis* Drew.

Host plants. None known.

Comments. Although all other species placed in this subgenus are being transferred to subgenus *Zeugodacus* (see below), molecular evidence (Krosch *et al*. 2012) suggests that *B. neopallescentis* and *B*. (*Z.*) *macrovittata* Drew form a closely related pair distinct from all other taxa included in the *Zeugodacus* group of subgenera. However, until the relationships of these species are better understood, we continue to retain *B. neopallescentis* in subgenus *Papuodacus* and *B. macrovittata* in subgenus *Zeugodacus*.

B. (*Papuodacus*) *neopallescentis* Drew

Dacus (*Hemizeugodacus*) *pallescentis* Drew, 1971: 44. Type locality Konedobu, Central Province, Papua New Guinea.

Bactrocera (*Papuodacus*) *neopallescentis* Drew, 1989: 193. New name for *Dacus pallescentis* Drew, preoccupied by *Dacus aberrans pallescentis* Hardy, 1955: 5.

Distribution. Papua New Guinea (Central, Morobe, Madang, West Sepik, East Sepik and Western Highlands Provinces) (Clarke *et al.* 2004).

Host plant. None recorded.

Male lure. Cue lure.

Comments. The basal scutellar setae are often weak and pale (Drew 1972a). For a detailed description and illustration see Drew (1971, 1989).

Excluded species

Five additional species included in *Papuodacus* by Drew and Romig (2013) are transferred here to subgenus *Zeugodacus*. For detailed morphological descriptions and illustrations of them see Drew and Romig (2013) and for an illustrated key to species see Drew and Romig (2016). Males of at least four of the species respond to cue lure (unknown for *B. maculifemur*).

Bactrocera (*Z.*) *complicata* White, 1999 is known only from West and East Timor (White and Evenhuis 1999, Drew and Romig 2013). It has either 1 or 2 pairs of scutellar setae and belongs in a complex with the costal band broadly expanded over the apex of cell r_{4+5} and the R-M and DM-Cu crossveins infuscated, close to species such as *B*. (*Z.*) *persignata* (Hering) from Sulawesi, Maluku and Flores.

Bactrocera (*Z.*) *fereuncinata* Drew & Romig, 2013 is known only from central Thailand (Drew and Romig 2013). With its distinctive abdominal pattern, it appears to be closely related to *B*. (*Z.*) *isolata* (Hardy) from SE Asia and *B*. (*Z.*) *juxtuncinata* Drew & Romig and *B*. (*Z.*) *uncinata* Drew & Romig from the Philippines. San Jose *et al*. (2018) placed *B. isolata* and *B. juxtuncinata* in the same clade on molecular grounds. *Bactrocera* (*Z.*) *isolata* breeds in the fruit of *Capparis* and *Maerua* (Capparaceae: Allwood *et al*. 1999) [others unknown].

Bactrocera (*Z.*) *maculifemur* (Hering, 1938) is known only from Kambaiti in northern Myanmar (Drew and Romig 2013). Originally referred to subgenus *Zeugodacus* by Norrbom *et al.* (1999) and transferred to *Papuodacus* by Drew and Romig (2013), this species morphologically appears to belong in the *B.* (*Z.*) *scutellaris* complex of Drew and Romig (2013).

Bactrocera (*Z.*) *ochrosterna* Drew & Romig, 2013 is known only from northern Vietnam (Drew and Romig 2013). Despite its pale abdomen, the wing, femoral, scutal and scutellar markings suggest a relationship with *B.* (*Z.*) *sinensis* and its allies (see below).

Bactrocera (*Z.*) *sinensis* Yu, Bai & Chen, 2011, described from Yunnan, China (Yu *et al.* 2011), was recorded from Peninsular Malaysia by Drew and Romig (2013). San Jose *et al*. (2018) placed in a clade with *B*. (*Z.*) *hatyaiensis* Drew & Romig and *B*. (*Z.*) *proprescutellata* Zhang, Chen & Gao.

Subgenus *Sinodacus* Zia

Sinodacus Zia, 1936: 157. Type species *Sinodacus hochii* Zia, 1936, by original designation.

Dacus (*Pacifodacus*) Drew, 1972a: 12. Type species *Asiadacus triangularis* Drew, 1968, by original designation. Syn. Drew 1989.

Definition. Abdominal sternite V of male with a slight to moderate posterior emargination; posterior lobe of male surstylus long; pecten of cilia on abdominal tergite III of male present; postpronotal setae absent; supra-alar setae present or absent; prescutellar acrostichal setae absent; one pair (apical) of scutellar setae (rarely with 1 or 2 basal setae present); scutum with postsutural medial yellow vitta present and presutural lateral yellow vittae present or absent; lateral yellow triangles present or absent; abdomen with tergite I often quadrate.

Response to male lures. Cue lure (14 species; one also to zingerone), methyl eugenol (1 species [error?]) or unknown (3 species).

Included species. *Bactrocera* (*S.*) *angusticostata* Drew, *B.* (*S.*) *brevipunctata* David & Hancock, *B*. (*S.*) *buvittata* Drew, *B*. (*S.*) *emarginata* (Perkins), *B.* (*S.*) *fuscans* (Wang) (newly transferred from *Asiadacus* Perkins), *B*. (*S.*) *hochii* (Zia), *B*. (*S.*) *infesta* (Enderlein), *B*. (*S.*) *longivittata* Chua & Ooi, *B*. (*S.*) *paulula* Drew, *B*. (*S.*) *sepikae* Drew, *B*. (*S.*) *speciosa* Drew & Romig, *B*. (*S.*) *spectabilis* Drew & Romig, *B*. (*S.*) *strigifinis* (Walker), *B*. (*S.*) *surrufula* Drew, *B.* (*S.*) *transversa* (Hardy), *B*. (*S.*) *triangularis* (Drew), *B*. (*S.*) *univittata* (Drew) and *B*. (*S.*) *whitei* Drew & Romig.

Host plants. Three species recorded from the fruit or flowers of Cucurbitaceae; others unknown.

Comments. The combination of shallow emargination to sternite V and long posterior surstylus lobe in males places *Sinodacus* in the *Zeugodacus* group of subgenera as defined by Drew (1989). Eastern species (New Guinea,

Solomon Islands and Australia) differ from western species (India and China to Sulawesi) in overall appearance, abdominal shape and smaller size; however, the two groups appear to be linked by species such as *B. sepikae* and *B. triangularis*, which have abdominal tergite I quadrate and *B. buvittata*, which has wing and scutal markings very similar to those of the Malaysian *B. longivittata*. Hence, at least for the time being, we retain *Pacifodacus* (which has *B. triangularis* as its type species) as a synonym of *Sinodacus*.

Included species

For detailed morphological descriptions and illustrations of all described species except *B. brevipunctata* and *B. fuscans* see Drew (1989) and Drew and Romig (2013). *Bactrocera brevipunctata* was illustrated by David *et al.* (2017) and *B. fuscans* in part by Wang (1988); the latter is illustrated further below (Fig. 1). Four species-groups are recognisable, based on wing pattern, facial and scutal markings, size and geographical distribution.

Group A

Medium-sized to large species (wing length *ca* 6.0-9.0 mm); wing with costal band expanded into a large apical patch that crosses vein M into cell m; scutum with postsutural medial yellow vitta not extending anterior to suture; presutural lateral yellow vittae absent; notopleural lobes yellow; face largely black, black banded or with a pair of black spots; femora black or fulvous; abdominal tergite I quadrate. India and southern China to the Philippines, Borneo and Sulawesi. Six species.

B. (*Sinodacus*) *brevipunctata* David & Hancock

Bactrocera (*Sinodacus*) *brevipunctata* David & Hancock, in David *et al*. 2017: 397. Type locality Konkan region, Maharashtra, India.

Distribution. Southwestern India (Maharashtra) (David *et al*. 2017).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species appears most similar to *B. hochii*, differing primarily in the reduced presutural yellow spots and fuscous apical third of all femora. It is the most westerly known species.

B. (*Sinodacus*) *fuscans* (Wang)

(Fig. 1)

Sinodacus fuscans Wang, 1988: 292-293 [Chinese] and 296 (English]. Type locality Xiaomengyang, Yunnan Province, China.

Bactrocera (*Asiadacus*) *fuscans* (Wang); Wang 1998: 59; Hancock and Drew 2018.

Distribution. Southern China (Yunnan) (Wang 1998).

Host plant. None recorded.

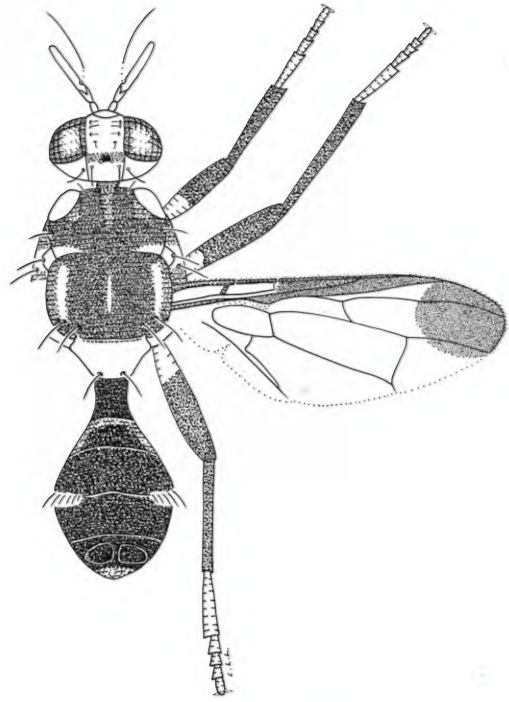

Fig. 1. *Bactrocera* (*Sinodacus*) *fuscans* (Wang), habitus of holotype male.

Male lure. None recorded.

Comments. This species was discussed by Hancock and Drew (2018), who removed it from synonymy with *B*. (*Tetradacus*) *brachycera* (Bezzi) and followed Wang (1998) in placing it in subgenus *Asiadacus* Perkins. It is returned here to its original subgenus *Sinodacus*, differing from all other species in lacking supra-alar setae (a characteristic of *Asiadacus*); however, its overall appearance, particularly the quadrate abdominal tergite I [slightly broader than indicated in Fig. 1], large size (wing length 6-8 mm), shape of the apical wing patch and largely black face are consistent with other species included in *Sinodacus.* Its habitus is illustrated in Fig. 1; male sternite V and terminalia were illustrated by Wang (1988) and the wing by Wang (1998).

B. (*Sinodacus*) *hochii* (Zia)

Sinodacus hochii Zia, 1936: 157. Type locality Hainan, China.

Dacus (*Pacifodacus*) *infestus*: Hardy 1973: 21; 1983: 31. Misidentifications (Thailand, Java).

Sinodacus quaternum Wang, 1988: 293. Type locality Fohai, Yunnan, China. Syn. Drew and Romig 2013: 252.

Sinodacus laterum Wang, 1988: 294. Type locality Hongtupo, Yunnan, China. Syn. Drew and Romig 2013: 252.

Bactrocera (*Sinodacus*) *hochii* (Zia); Liang *et al*. 1993: 139; Drew and Romig 2013: 252.

Sinodacus hainanus Chao & Lin, 1996: 126. Type locality Baoting, Hainan, China. Syn. Norrbom *et al*. 1999: 100.

Sinodacus qionganus Chao & Lin, 1996: 127. Type locality Baoting, Hainan, China. Syn. Drew and Romig 2013: 252.

Sinodacus jinreni Chao & Lin, 1996: 128. Type locality Tiandeng, Guangxi, China. Syn. Drew and Romig 2013: 252.

Sinodacus rubzovi Chao & Lin, 1996: 129. Type locality Tiandeng, Guangxi, China. Syn. Drew and Romig 2013: 252.

Sinodacus jiannanus Chao & Lin, 1996: 130. Type locality Luodian, Guizhou, China. Syn. Drew and Romig 2013: 252.

Distribution. Southern China (Yunnan, Guangzi, Guizhou, Hainan), Bangladesh, Thailand, Vietnam, Peninsular Malaysia, Indonesia (Sumatra, Java, Sumba) (Drew and Romig 2013, Leblanc *et al*. 2014, Hering 1952).

Host plants. Fruit of *Gymnopetalum cochinchinensis*, *Luffa aegyptiaca* and *Trichosanthes wawraei* (Cucurbitaceae) (Allwood *et al*. 1999).

Male lures. Cue lure and zingerone (Drew and Romig 2013, Doorenweerd *et al.* 2018).

Comments. This is a variable species, characterised by a transverse black band on the face, scutum with triangular sutural yellow spots connected to the notopleural lobes and a short and ovate postsutural medial yellow spot and pale femora without fuscous markings. Lateral postsutural vittae are normally absent but faint indications sometimes occur and the scutellum sometimes has a pair of weak basal setae; these characters have led to the prolific synonymy noted above. Hardy (1983) noted the presence of at least one prescutellar acrostichal seta in a specimen from Java [as *B. infesta*].

B. (*Sinodacus*) *infesta* (Enderlein)

Polistomimetes infesta Enderlein, 1920: 359. Type locality Deli, Sumatra, Indonesia.

Bactrocera (*Sinodacus*) *infesta* (Enderlein); Norrbom *et al*. 1999: 100.

Distribution. Thailand, Vietnam, Peninsular Malaysia and Indonesia (Sumatra, Java) (Drew and Romig 2013).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species is characterised by the presence of facial spots, distinct lateral postsutural yellow vittae, a short and ovate postsutural medial yellow spot and largely black femora. Records from Thailand and Java listed by Hardy (1973, 1983) are of *B. hochii*.

B. (*Sinodacus*) *transversa* (Hardy)

Dacus (*Pacifodacus*) *transversus* Hardy, 1982: 192. Type locality Lindu Valley, central Sulawesi, Indonesia.

Bactrocera (*Sinodacus*) *transversa* (Hardy); Norrbom *et al*. 1999: 101.

Distribution. Indonesia (Sulawesi) (Drew and Romig 2013).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species is easily recognised by the transverse and posterior, rather than longitudinal and medial, postsutural vitta. Abdominal tergite I in an examined paratype is quadrate as in other Group A species and the abdomen closely resembles that of *B. whitei* in shape, not as illustrated in Drew and Romig (2013). Hardy (1982) noted the presence of 3 scutellar setae in one specimen, suggesting a possible placement in *Paradacus* Perkins and *B. transversa* bears a superficial resemblance to another Sulawesi endemic, *B.* (*Paradacus*) *hancocki* Drew & Romig; however, this is considered here to be a case of convergence and the species is retained in *Sinodacus*.

B. (*Sinodacus*) *whitei* Drew & Romig

Bactrocera (*Sinodacus*) *whitei* Drew & Romig, 2013: 258. Type locality Mt Makiling, Luzon, Philippines.

Distribution. Philippines (Luzon) and East Malaysia (Sabah) (Drew and Romig 2013).

Host plant. None recorded.

Male lure. Cue lure.

Comments. The posteriorly expanded (triangular) medial and short lateral postsutural yellow vittae on the scutum suggest an affinity between this species and the Sulawesian *B. transversa*.

Group B

Medium-sized species (wing length *ca* 5.6-6.4 mm); wing with costal band broadly crossing vein R_{4+5} at least over apical half of cell r_{4+5} but not expanded into a large apical patch extending into cell m; scutum with postsutural medial yellow vitta extending presuturally anterior to line of anterior notopleural setae; presutural lateral yellow vittae present and connecting postpronotal and notopleural lobes; notopleural lobes yellow; face largely black or with a pair of black spots; all femora either extensively black or entirely fulvous; abdominal tergite I quadrate. Peninsula Malaysia, Borneo and the Philippines. Three species.

B. (*Sinodacus*) *longivittata* Chua & Ooi

Bactrocera (*Sinodacus*) *longivittata* Chua & Ooi, 1998: 487. Type locality Hulu Langat, Selangor, Peninsular Malaysia.

Distribution. Peninsular Malaysia (Drew and Romig 2013).

Host plant. None recorded.

Male lure. The type and only known specimen was recorded at methyl eugenol (Chua and Ooi 1998) but this requires confirmation.

Comments. This species differs from *B. speciosa* and *B. spectabilis* in the entirely fulvous femora and fulvous face with only small black spots (femora and face largely black in the other species).

B. (*Sinodacus*) *speciosa* Drew & Romig

Bactrocera (*Sinodacus*) *speciosa* Drew & Romig, 2013: 256. Type locality Mt Kinabalu, Sabah, East Malaysia.

Distribution. East Malaysia (Sabah) (Drew and Romig 2013).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species differs from the similar *B. longivittata* and *B. spectabilis* in having the costal band only marginally entering cells br and r_{4+5} in its basal half (broadly so in the other species).

B. (*Sinodacus*) *spectabilis* Drew & Romig

Bactrocera (*Sinodacus*) *spectabilis* Drew & Romig, 2013: 256. Type locality Mt Makiling Botanic Gardens, Luzon, Philippines.

Distribution. Philippines (Luzon) (Drew and Romig 2013).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species differs from the similar *B. longivittata* and *B. spectabilis* in having the scutum red-brown with elongate black vittae and presutural spots (largely non-vittate black in the other species).

Group C

Small to medium-sized species (wing length *ca* 4.5-5.7 mm [5.2-6.4 in *B. strigifinis*]); wing with costal band narrow and crossing vein R_{4+5} only at extreme apex [except in *B. buvittata*]; presutural lateral yellow vittae present and connecting postpronotal and notopleural lobes; notopleural lobes yellow; face fulvous with a pair of black spots [except black in *B. buvittata*]; only hind femora black or all femora fulvous; abdominal tergite I usually not quadrate. Northern Moluccas to Papua New Guinea, Solomon Islands and NE Australia. Seven species.

B. (*Sinodacus*) *buvittata* Drew

Bactrocera (*Sinodacus*) *buvittata* Drew, 1989: 203. Type locality 51 km NW of Port Moresby, Central Province, Papua New Guinea.

Distribution. Papua New Guinea (Central, Morobe and Madang Provinces) (Clarke *et al*. 2004).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species closely resembles the Malaysian *B. longivittata* in size (5.4 and 5.6 mm respectively), pale femora, scutal markings and broad costal band, suggesting a close relationship. However, it differs in the black face, broader medial vitta and paler abdomen with a non-quadrate tergite I and the resemblance is regarded here as a result of convergence. Drew (1989) suggested an affinity with the two species in Group D below.

B. (*Sinodacus*) *emarginata* (Perkins)

Neodacus emarginatus Perkins, 1939: 24. Type locality Mondo, Central Province, Papua New Guinea.

Bactrocera (*Sinodacus*) *emarginata* (Perkins); Drew 1989: 204.

Distribution. Papua New Guinea (Central Province) (Drew 1989).

Host plant. None recorded.

Male lure. None recorded.

Comments. This species resembles *B. surrufula* in having the apical half of the wing extensively (pale) fuscous (with a distinctly darker costal band and anal streak) but differs in the paler abdomen and entirely pale femora.

B. (*Sinodacus*) *sepikae* Drew

Bactrocera (*Sinodacus*) *sepikae* Drew, 1989: 206. Type locality Eliptamin, West Sepik Province, Papua New Guinea.

Distribution. Papua New Guinea (West Sepik Province) (Drew 1989).

Host plant. None recorded.

Male lure. None recorded. The type and only known specimen was hand collected on cardamom (*Elattaria cardamomum*: Zingiberaceae).

Comments. This species shares with *B. triangularis* an ovate abdomen with a quadrate tergite I, narrow transverse wing bands and isolated medial black spot on abdominal tergite V. It differs in the entirely yellow postpronotal and notopleural lobes and the narrow postsutural lateral and narrowly triangular medial yellow vittae on the scutum.

B. (*Sinodacus*) *strigifnis* (Walker)

Dacus strigifinis Walker, 1861: 295. Type locality Bachan, Maluku, Indonesia.

Neodacus lanceolatus Perkins, 1939: 22. Type localities Mondo, Kokoda, Ishurava and Mt Lamington, Northern Province, Papua New Guinea. Syn. Norrbom *et al.* 1999: 101.

Dacus (*Chaetodacus*) *albolateralis* Malloch, 1939: 413. Type locality Upper Watut, Morobe Province, Papua New Guinea. Syn. Norrbom *et al.* 1999: 101.

Neodacus strigifinis atritus May, 1962: 65. Type locality Aiyura, Eastern Highlands, Papua New Guinea. Syn. Norrbom *et al.* 1999: 101.

Bactrocera (*Sinodacus*) *strigifinis* (Walker); Drew 1989: 207.

Distribution. Eastern Indonesia (northern Maluku: Bacan and Papua Province: Biak) (Drew 1989, White and Evenhuis 1999), Papua New Guinea (West Sepik, East Sepik, Madang, Morobe, Central, Gulf, Milne Bay and Northern (Oro) Provinces) (Clarke *et al.* 2004) and NE Australia from Torres Strait to Ayr, Queensland (Hancock *et al.* 2000).

Host plant. Reared from flowers of *Cucurbita pepo* (Cucurbitaceae) (Leblanc *et al.* 2012).

Male lure. Cue lure.

Comments. This species is the most widely distributed; it is easily recognised by its overall pale appearance with an isolated medial black spot on abdominal tergite V and wing with crossvein DM-Cu narrowly fuscous.

B. (*Sinodacus*) *surrufula* Drew

Bactrocera (*Sinodacus*) *surrufula* Drew, 1989: 208. Type locality Wau Ecology Institute, Morobe Province, Papua New Guinea.

Distribution. Papua New Guinea (Western Highlands, Eastern Highlands, Southern Highlands, Enga, Morobe and Central Provinces) (Clarke *et al.* 2004).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species is distinguished by its elongate and almost entirely black abdomen, extensive fuscous marking over the apical half of the wing and black hind femora, the other femora fulvous.

B. (*Sinodacus*) *triangularis* (Drew)

Asiadacus triangularis Drew, 1968: 192. Type locality New Britain, Papua New Guinea.

Bactrocera (*Sinodacus*) *triangularis* (Drew); Drew 1989: 209.

Distribution. Papua New Guinea (West New Britain, East New Britain, New Ireland and Bougainville) (Clarke *et al.* 2004).

Host plant. Reared from flowers of *Cucurbita pepo* (Cucurbitaceae) (Leblanc *et al.* 2012).

Male lure. Cue lure and (weakly) zingerone.

Comments. This species shares with *B. sepikae* an ovate abdomen with a quadrate tergite I, narrow transverse wing bands and isolated medial black spot on abdominal tergite V. It differs in the partly fulvous postpronotal and notopleural lobes, lack of postsutural lateral yellow vittae and the very broadly triangular postsutural medial yellow vitta on the scutum. Supra-alar setae are sometimes absent (Drew 1968).

B. (*Sinodacus*) *univittata* (Drew)

Dacus (*Pacifodacus*) *univittatus* Drew, 1972b: 189. Type locality Kieta, Bougainville.
Bactrocera (*Sinodacus*) *univittata* (Drew); Drew 1989: 209.

Distribution. Papua New Guinea (Bougainville) and Solomon Islands (Shortland Is, Guadalcanal, Makira, Santa Isabel and Western Province) (Drew 1989, Drew and Romig 2001).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species resembles *B. triangularis* in its overall pale coloration, vestigial or absent postsutural lateral yellow vittae and islolated black spot on abdominal tergite V. It differs in the non-quadrate abdominal tergite I, narrow rather than broadly triangular postsutural medial yellow vitta and lack of fuscous transverse wing bands. Specimens recorded from Solomon Islands by Drew (1989) as possibly *B. strigifinis* were referred to *B. univittata* by Drew and Romig (2001), who noted the occasional presence of weak lateral postsutural yellow vittae.

Group D

Small species (wing length *ca* 4.2-5.2 mm); wing with costal band narrow and reaching apex of vein M but not expanded apically; scutum with medial yellow vitta not or at most slightly extending anterior to suture; presutural lateral yellow vittae absent; notopleural lobes black; face fulvous and unspotted; femora entirely fulvous; abdominal tergite I not quadrate. Papua New Guinea. Two species.

B. (*Sinodacus*) *angusticostata* Drew

Bactrocera (*Sinodacus*) *angusticostata* Drew, 1989: 202. Type locality Kassam Pass, Eastern Highlands Province, Papua New Gunea.

Distribution. Papua New Guinea (Eastern Highlands, Western Highlands, Southern Highlands, Enga and Morobe Provinces) (Clarke *et al*. 2004).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species shares with *B. paulula* a black notopleural lobe, differing in the largely red-brown scutum and restriction of the medial black abdominal vitta to tergite V.

B. (*Sinodacus*) *paulula* Drew

Bactrocera (*Sinodacus*) *paulula* Drew, 1989: 204. Type locality Gumi-Watut, Morobe Province, Papua New Gunea.

Distribution. Papua New Guinea (Eastern Highlands, Western Highlands, Southern Highlands, Enga and Morobe Provinces) (Clarke *et al*. 2004).

Host plant. None recorded.

Male lure. Cue lure.

Comments. This species shares with *B. angusticostata* a black notopleural lobe, differing in the largely black scutum and presence of the medial black vitta on abdominal tergites III-V.

Excluded species

Two species, *B. bogorensis* (Hardy) from Bangladesh and Indonesia and *B. hamaceki* Drew & Romig from the Solomon Islands, do not fit the concept of *Sinodacus* as recognised here and are transferred to subgenus *Zeugodacus*.

Bactrocera (*Zeugodacus*) *bogorensis* was described in subgenus *Zeugodacus* by Hardy (1983). It was transferred to *Sinodacus* by Drew and Romig (2013), who included '*Dacus*' (*Zeugodacus*) *ascitus* Hardy as a synonym. *Bactrocera* (*Z.*) *bogorensis* differs from all other species of *Sinodacus* in having the prescutellar acrostichal setae either present or absent and a broad anal stripe on the wing that narrows medially and expands posteriorly. This latter character is typical of many species included in subgenus *Zeugodacus* and we regard the absence of the prescutellar acrostichal setae in some specimens as a homoplasious condition. It is known from Bangladesh, Sumatra, Java and Sulawesi and males respond to cue lure (Drew and Romig 2013, Leblanc *et al*. 2014). It further differs from typical western *Sinodacus* species in lacking the quadrate abdominal tergite I and in the narrow costal band that is not broadly expanded apically; both these characters are typical of subgenus *Zeugodacus*.

Bactrocera (*Zeugodacus*) *hamaceki* was placed in subgenus *Sinodacus* by Drew and Romig (2001) because it has only 1 pair of scutellar setae and lacks prescutellar acrostichal setae. However, it is distinctly larger (wing length *ca* 8 mm) than other eastern *Sinodacus* species and has the combination of presutural lateral yellow vittae absent, facial spots present and a broad costal band that reaches vein R_{4+5} and widens along the wing margin to the apex of vein M. It is known only from the Solomon Islands and males respond to cue lure (Drew and Romig 2001). *Bactrocera* (*Z.*) *hamaceki* is very similar to

B. (*Z*.) *abdoangusta* (Drew) and *B*. (*Z*.) *fuscipennula* Drew & Romig, both also occurring in the Solomon Islands and with very similar wing and body patterns, the latter pair differing primarily in the presence of 2 pairs of scutellar setae. Significantly, prescutellar acrostichal setae are sometimes absent in *B. fuscipennula* and supra-alar setae are sometimes absent in both *B. fuscipennula* and *B. abdoangusta* (Drew and Romig 2001, Drew 1972b), suggesting that all three species form a closely-related trio. Supra-alar, prescutellar acrostichal and basal scutellar setae are also either present or absent in the similarly patterned *B*. (*Z*.) *cucurbitae* (Coquillett) (White 1999) and these character states are clearly variable within *Bactrocera*.

Key to species in subgenus *Sinodacus*

For an illustrated key to SE Asian species see Drew and Romig (2016).

1 Wing with costal band expanded at apex into a large spot crossing vein M into cell m 2

– Wing with costal band broad or narrow but not expanded at apex into a large spot crossing vein M into cell m 7

2 Scutum red-brown with a small ovate postsutural medial vitta 3

– Scutum black with medial vitta variable but not small and ovate 5

3 Face with a pair of black spots; scutum with lateral postsutural vittae long, parallel-sided and ending behind intra-alar setae; femora mostly black over apical two-thirds [SE Asia] ..... *B*. (*S*.) *infesta* (Enderlein)

– Face with a transverse black band; scutum with lateral postsutural vittae absent or vestigial and ending well before intra-alar setae; femora mostly fulvous to red-brown, at most black over apical third 4

4 Scutum with yellow triangle along suture connected to notopleural lobe; femora entirely fulvous to red-brown [SE Asia] ..... *B*. (*S*.) *hochii* (Zia)

– Scutum with yellow spot along suture separated from notopleural lobe; femora with apical third fuscous to black [SW India] .... *B*. (*S*.) *brevipunctata* David & Hancock

5 Face mostly black; scutum with medial postsutural vitta narrow and elongate and lateral postsutural yellow vittae elongate, parallel-sided and extending almost to intra-alar setae; wing with costal band not or only faintly crossing vein R_{2+3} and not broadly united with the large apical spot (Fig. 1) [southern China] ..... *B*. (*S*.) *fuscans* (Wang)

– Face with a pair of black spots and sometimes a band across oral margin; scutum with medial postsutural vitta broadly triangular or reduced to a narrow transverse bar and lateral postsutural yellow vittae short, triangular and at most slightly extending beyond line of supra-alar setae; wing with costal band crossing vein R_{2+3} to vein R_{4+5} and broadly united with the large apical spot 6

6 Scutum with medial postsutural vitta reduced to a narrow and transverse prescutellar bar, yellow triangle along suture connected to notopleural lobe and postpronotal lobes fuscous [Sulawesi] .... *B.* (*S.*) *transversa* (Hardy)

– Scutum with medial postsutural vitta broadly triangular, yellow triangle along suture separated from notopleural lobe and postpronotal lobes yellow [Philippines and Sabah] ..... *B.* (*S.*) *whitei* Drew & Romig

7 Scutum without lateral presutural yellow vittae connecting postpronotal and notopleural lobes; notopleural lobes black; wing with costal band very narrow and extending around apex to vein M; face fulvous without black markings 8

– Scutum with lateral presutural yellow vittae connecting postpronotal and notopleural lobes; notopleural lobes yellow or partly fulvous; wing with costal band variable in width; face largely black, black-banded or with a pair of black spots 9

8 Scutum red-brown with at most indistinct fuscous markings anteriorly; abdomen with medial black vitta confined to tergite V and without a black band across base of tergite III connecting the black lateral margins [Papua New Guinea] ..... *B.* (*S.*) *angusticostata* Drew

– Scutum black; abdomen with medial black vitta on tergites III-V and with a black band across base of tergite III connecting the black lateral margins [Papua New Guinea] ..... *B.* (*S.*) *paulula* Drew

9 Wing with a broad costal band crossing vein R_{4+5} at least in apical half of cell r_{4+5}; face with a pair of black spots or largely black 10

– Wing with a narrow costal band not crossing vein R_{4+5} except at extreme apex; face fulvous with a pair of often small black spots 13

10 Legs entirely fulvous; face fulvous with a pair of black spots or black; scutum with medial postsutural yellow vitta expanded and rounded posteriorly; wing with costal band broadly and uniformly crossing vein R_{4+5} into cells br and r_{4+5} 11

– Legs largely black, especially the hind femora; face largely fuscous to black with darker lines; scutum with medial postsutural yellow vitta narrow and linear, not expanded posteriorly; wing with costal band of variable width in cells br and r_{4+5} 12

11 Face black; abdomen with black markings restricted to tergite V as a medial spot and apex; ceromata black [Papua New Guinea] .... *B.* (*S.*) *buvittata* Drew

– Face fulvous with a pair of black spots; abdomen with black markings present as a transverse basal band on tergite III connected to a medial vitta on tergites III-V and isolated anterolateral corners of tergites IV and V; ceromata fulvous [West Malaysia] ..... *B.* (*S.*) *longivittata* Chua & Ooi

12 Wing with costal band broadly and uniformly crossing vein R_{4+5} into cells br and r_{4+5}; scutum red-brown with longitudinal black submedial and dorsocentral vittae, prescutellar margin and presutural patches [Philippines: Luzon] ..... *B.* (*S.*) *spectabilis* Drew & Romig

– Wing with costal band at most weakly crossing vein R_{4+5} into cell br and basal half of cell r_{4+5} before expanding into apical half of cell r_{4+5}; scutum entirely black except for yellow markings [East Malaysia: Sabah] .... *B.* (*S.*) *speciosa* Drew & Romig

13 Wing with apical half broadly fuscous and the costal band reaching vein R_{4+5} along its entire length; scutum black except for yellow lobes and vittae; abdomen with a black medial vitta and lateral margins over at least tergites IV and V; ceromata dark fuscous or black..... 14

– Wing with apical half not broadly fuscous and the costal band often not reaching vein R_{4+5}except at apex; scutum often largely or entirely fulvous; abdomen fulvous with an isolated black spot on tergite V; ceromata fulvous..... 15

14 Abdomen elongate-oval and largely fuscous with a black medial vitta and broad lateral margins on tergites III-V; legs with hind femora fuscous except extreme apex [Papua New Guinea] ..... *B.* (*S.*) *surrufula* Drew

– Abdomen oval and largely fulvous to orange-brown with a fuscous medial vitta and lateral margins confined almost entirely to tergites IV and V; legs with all femora fulvous [Papua New Guinea] .... *B.* (*S.*) *emarginata* (Perkins)

15 Abdomen globose, with tergite I quadrate; wing with narrow transverse bands across R-M and DM-Cu crossveins 16

– Abdomen oval, with tergite I not quadrate; wing without narrow transverse bands across R-M and DM-Cu crossveins, at most with isolated infuscations over R-M and/or DM-Cu crossveins only.....17

16 Scutum brown to black; postpronotal and notopleural lobes entirely yellow; postsutural medial yellow vitta elongate, not broadly triangular and narrow lateral yellow vittae present; wing with costal band broad, reaching vein R_{4+5} over most of its length [NW Papua New Guinea] .... *B.* (*S.*) *sepikae* Drew

– Scutum fulvous; postpronotal and notopleural lobes partly fulvous; postsutural medial yellow vitta broadly triangular and lateral yellow vittae absent; wing with costal band narrow, not reaching vein R_{4+5} except at extreme apex [eastern Papua New Guinea: Bismarcks and Bougainville] ..... *B.* (*S.*) *triangularis* (Drew)

17 Scutum with lateral postsutural yellow vittae broad, reaching almost to intra-alar setae and extending across suture anteriorly; wing with DM-Cu crossvein distinctly infuscated and R-M crossvein bare; facial spots small

[E. Indonesia: northern Maluku, Papua Province; Papua New Guinea and NE Australia].....l..... *B.* (*S.*) *strigifinis* (Walker)

– Scutum with lateral postsutural vittae absent or vestigial, neither reaching intra-alar setae nor extending across suture anteriorly; wing with R-M and DM-Cu crossveins both weakly infuscated; facial spots large [Solomon Islands and Bougainville] ..... *B.* (*S.*) *univittata* (Drew)

Discussion

Relationships of the small to medium-sized species of the *Zeugodacus* group of subgenera in the Papuan region are problematical. It is possible that *Papuodacus*, *Niuginidacus*, the eastern *Sinodacus* species (Groups C and D [= *Pacifodacus* Drew]) and some of the Papuan species in subgenus *Zeugodacus* (*e.g. B. macrovittata* Drew, *B. citroides* Drew and *B. unilateralis* Drew) form a monophyletic grouping with multiple homoplasy in the presence or absence of supra-alar, prescutellar acrostichal and basal scutellar setae. It is also possible that all these taxa breed in Cucurbitaceae flowers and are more closely related to *Asiadacus* and typical *Zeugodacus* (*i.e. B. caudata* and the *scutellaris* complex) than to the fruit-infesting species of the *tau-cucurbitae* assemblage and subgenera such as *Austrodacus*, *Diplodacus*, typical *Sinodacus* (Group A) and *Javadacus* Hardy. Such a relationship was also suggested on molecular grounds by San Jose *et al.* (2018).

The four groups of subgenus *Sinodacus* form recognisably monophyletic units. The western Group A, with its large apical spot, is the most distinctive, with *B. brevipunctata* from SW India and *B. hochii* from Bangladesh-SE Asia representing a species pair. The Philippines-Sabah *B. whitei* and Sulawesian *B. transversa* have the postsutural medial vitta broadened posteriorly and also appear to form a species pair, as do *B. fuscans* from China and *B. infesta* from Thailand and Vietnam to Indonesia, the latter pair united by their elongate lateral and narrow medial postsutural yellow vittae, mostly black femora and fuscous tibiae. The only recorded host plants (for *B. hochii*) are the fruit of Cucurbitaceae.

Group B is distinguished by its broad costal band and contains three species from Peninsular Malaysia, Philippines and Borneo, with *B. spectabilis* and *B. speciosa* forming a species pair. No host plants have been recorded and this group appears to be intermediate between Groups A and C+D, sharing the presence of a quadrate abdominal segment 1 with Group A and presutural lateral yellow vittae with Group C. Without host plant or molecular data, it is not possible to decide at present whether this group is closer to typical western *Sinodacus* than to the eastern *Pacifodacus* groups.

The eastern Groups C and D appear to be related, although the absence of both prescutellar acrostichal and basal scutellar setae is a possibe homoplasy and Group D, which lacks the presutural lateral yellow vittae connecting the postpronotal and notopleural lobes, might be closer to typical members of

subgenus *Zeugodacus* (*i.e*. including the type-species *B. caudata* (Fabricius)). The only recorded host plants (for *B. strigifinis* and *B. triangularis*) are the flowers of Cucurbitaceae (as for *B. caudata*); this and well-supported molecular studies by San Jose *et al.* (2018) suggest that these eastern groups are indeed separate from at least the western Group A (typical *Sinodacus*). Further study of subgenus *Zeugodacus* will likely resolve this issue.

The *Zeugodacus* group is considered here to comprise 14 subgenera, referred to two subgroups: (1) *Aglaodacus* Munro, *Heminotodacus* Drew, *Nesodacus* Perkins, *Paradacus* Perkins, *Parasinodacus* Drew & Romig and *Perkinsidacus* Hancock & Drew, all lacking the medial postsutural yellow vitta and all possibly (at least primarily) with non-cucurbitaceous host plants (Hancock and Drew 2017c); and (2) *Asiadacus* Perkins, *Austrodacus* Perkins, *Diplodacus* May, *Javadacus* Hardy, *Niuginidacus* Drew, *Papuodacus* Drew, *Sinodacus* Zia and *Zeugodacus* Hendel, all with the medial yellow vitta present and (primarily) with Cucurbitaceae host plants. It is likely that the Indian *B.* (*Paradacus*) *duplicata* (Bezzi) is an aberrant species of *Parasinodacus* with 2 pairs of scutellar setae.

Except for the Madagascan *Aglaodacus*, all subgenera are Indo-Australian in origin and the number of included species and their biogeographical distributions are listed in Table 1. Previous Indo-Australian subgenera were reviewed by Hancock and Drew (2016, 2017a-c). *Javadacus* and *Sinodacus* are clearly polyphyletic with regard to *Zeugodacus* (Hancock and Drew 2017a, San Jose *et al*. 2018) and the limits of these subgenera require further investigation. The group is well represented and most speciose in South-East Asia (Zone B), particularly the cucurbit-feeding subgroup (2); however, the presence of the Madagascan *Aglaodacus* suggests that subgroup (1) [likely plesiomorphic and represented by ancestral *Parasinodacus*] arose in India. The *Zeugodacus* group, retaining the plesiomorphic TAA stop codon to the COI gene (Jiang *et al*. 2016), is evidently primitive and Drew and Hancock (1999) suggested that genus *Bactrocera* s.l. [*i.e*. as ancestral '*Zeugodacus*'] arose in India as a rainforest fruit-feeder alongside the asclepiad-feeding *Dacus* Fabricius, a view supported by molecular studies (Krosch *et al.* 2012). Both molecular and morphological evidence (Krosch *et al.* 2012, Hancock and Drew 2018) suggest that the ancestor of the *Melanodacus* and *Bactrocera* groups of subgenera, subgenus *Tetradacus* Miyake [all with the apomorphic TA stop codon: Jiang *et al*. 2016], also originated in India.

The Cucurbitaceae are believed to have originated in mainland Asia during the Cretaceous (Schaefer *et al.* 2009) and, while apparently absent from India and thus unavailable as host plants during the initial evolution of subgroup (1) [and of *Dacus*, regarded ancestrally as asclepiad-feeders by Hancock and Drew (2006)], this would have facilitated the subsequent evolution and diversification of the cucurbit-feeding subgroup (2) in SE Asia and beyond after unification of India with Asia *ca* 50-35 Mya.

Table 1. List of subgenera in the *Zeugodacus* group as currently recognised, total number of species and number of species recorded from Africa (including Madagascar) and the Indo-Australian biogeographic Zones A-F as detailed by Hancock and Drew (2015): A = Indian subcontinent; B = South-East Asia; C = Wallacea; D = New Guinea-Solomons; E = Australia; F = South Pacific. Note that *Javadacus* and *Sinodacus* are polyphyletic with respect to *Zeugodacus*.

Subgenus	Total spp	Africa	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Subgroup (1)								
Aglaodacus	**1**	1[1]	0	0	0	0	0	0
Heminotodacus	**1**	0	0	0	0	1	0	0
Nesodacus	**1**	0	0	1	0	0	0	0
Paradacus	**7**	0	1[2]	1	5	1	0	0
Parasinodacus	**19**[3]	0	2	9	3	4	0	1
Perkinsidacus	**2**	0	0	0	1	1	0	0
Subgroup (2)								
Asiadacus	**2**	0	0	2	1	0	0	0
Austrodacus	**5**	0	0	0	0	4	1	0
Diplodacus	**1**	0	0	0	0	0	1	0
Javadacus	**5**	0	2	3	1	0	0	0
Niuginidacus	**1**	0	0	0	0	1	0	0
Papuodacus	**1**	0	0	0	0	1	0	0
Sinodacus	**19**	0	2	7	3	9	1	0
Zeugodacus	**136**[4]	1[5]	23	85	32	19	2	1
TOTAL SPECIES	**201**	**2**	**30**	**108**	**46**	**41**	**5**	**2**

[1]Madagascar; [2]the Indian *B. duplicata* (Bezzi) likely belongs in *Parasinodacus*; [3]includes *B. disturgida* Yu, Deng & Chen, 2012 from China (following Doorenweerd *et al.* 2018) [close to *B. incisa* (Walker)] but excludes *B. pseudocucurbitae* White, 1999, which was returned to subgenus *Bactrocera* by Doorenweerd *et al.* (2018) on reliable molecular evidence (San Jose *et al.* 2018); [4]includes *B. anala* Chen & Zhou, 2013 from China (following Doorenweerd *et al.* 2018) but excludes *B. luteicinctuta* Ito, 2011 from Nepal, a probable synonym of *B. yoshimotoi* (Hardy); [5]the sole African species (*B. cucurbitae* (Coquillett)) is an adventive introduced from India.

Although not conclusive, molecular dating by Krosch *et al.* (2012) suggests that the *Tetradacus-Melanodacus-Bactrocera* lineage arose at an equivalent time to the *Zeugodacus* group alone [mean estimates 69 and 68.6 Mya respectively] and after the *Dacus-Zeugodacus* split [mean estimate 72.2 Mya], not before it as current analyses of molecular data imply. This, together with their non-cucurbitaceous ancestral host plants and morphological evidence, casts doubt on the association of *Zeugodacus* with *Dacus* rather than with *Bactrocera*. The similar ages of the *Tetradacus-Melanodacus-Bactrocera* and *Zeugodacus* lineages are compatible with a

sister relationship. Whereas the *Zeugodacus* group likely did not radiate into South-East Asia until after union with the Indian plate and availability of cucurbitaceous host plants (*ca* 35 Mya), the 'glancing blow' between India and Sumatra-Borneo *ca* 57 Mya (Krosch *et al*. 2012) would have enabled ancestral *Tetradacus* to colonise SE Asia (Sundaland) as the ancestor of the *Melanodacus* group of subgenera, subgenus *Hemizeugodacus* Hardy, which is not known west of Sundaland and was considered to be plesiomorphic by Hancock and Drew (2018). Eastward dispersal to the Papuan Subregion appears to have resulted in the differentiation of the *Bactrocera* group of subgenera, possibly centred on subgenus *Apodacus* Perkins (Hancock and Drew 2018), which has male sternite V less deeply emarginate than is usual in that group of subgenera and shares with *Hemizeugodacus* the presence of a medial yellow vitta on the scutum.

Whereas most subgenera have remained small, subgenera *Zeugodacus* s.s. and *Bactrocera* s.s. have radiated explosively into cucurbits and rainforest fruit respectively, the recent nature of these radiations often obscuring their genetic differentiation, such as in the three species complexes within subgenus *Bactrocera* noted by Leblanc *et al*. (2015) – *tryoni-neohumeralis* in Australia, plus *dorsalis-invadens-carambolae-papayae* and *osbeckiae-melastomatos-rubigina* in SE Asia – which could not be differentiated on the genes examined but showed morphological [and often biological] characters that enabled their separation.

Acknowledgements

We thank Susan Wright (Queensland Museum, Brisbane) and Daniel Whitmore (Natural History Museum, London) for access to specimens in their care and Christine Lambkin (Queensland Museum) for preparing Figure 1 from an original sketch by DLH.

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NEW RECORDS OF *MELANOSTOMA FUMIVENOSUM* DOESBURG (DIPTERA: SYRPHIDAE) WITH THE DESCRIPTION OF THE MALE

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Abstract

The first records of *Melanostoma fumivenosum* Doesburg since its original description are given. The newly studied specimens, collected in Papua New Guinea, are new records for this country and include the first known males. A full re-description is provided as well as some images, including drawings of male genitalia.

Introduction

Flower flies are one of the richest families of Diptera in number of species, with more than 6,200 described valid species (Thompson 2013). Also known as hover flies in Europe, the adults are frequent and effective flower visitors and are considered important pollinators (Ssymank and Kearns 2009, Inouye *et al*. 2015) and they have been used as bioindicators to assess the loss of biodiversity and the efficiency of restoration and conservation policies (Sommaggio 1999, Tscharntke *et al*. 2005, Ricarte *et al*. 2011, Sommaggio and Burgio 2014). Syrphid larvae play an important role as biological control agents of pests (Schmidt *et al*. 2004, Bergh and Short 2008, Nelson *et al*. 2012, Eckberg *et al*. 2015) and as decomposers of organic matter (Lardé 1989, Martínez-Falcón *et al*. 2012).

The genus *Melanostoma* Schiner comprises more than 50 valid species (Thompson 2013, Thompson *et al*. 2017, Ramage *et al*. in press), which are among the most abundant and conspicuous flower flies in the northern Palaearctic Region (Haarto and Ståhls 2014). Larvae of this genus have been found feeding on several prey, mostly aphids but also on mites, psyllids, plant bugs and larvae of beetles and other flies (Rojo *et al*. 2003). Despite their abundance, *Melanostoma* species are not easy to identify due to presence of melanic forms, coloration variability and taxonomic history with many synonyms (Haarto and Ståhls 2014). Moreover, recent DNA barcode studies have shown that different species may share haplotypes for the cytochrome c oxidase gene (COI) and additional molecular markers are needed to reliably identify the taxa based on molecules (Haarto and Ståhls 2014).

In the Australasian and Oceanic Regions five *Melanostoma* species occur (Ramage *et al*. 2018), namely *M. apicale* Bigot, 1884 (found in Australia, Fiji, New Caledonia, Papua New Guinea, Solomon Islands, Tonga and Samoa), *M. fasciatum* (Macquart, 1850) (New Zealand), *M. fumivenosum* Doesburg, 1966 (New Guinea Island), *M. polynesiotes* Mengual & Ramage, 2018 (French Polynesia) and *M. univittatum* (Wiedemann, 1824) (India, Sri Lanka, Thailand, Taiwan, Philippines, Borneo, Java and Central Moluccas).

Since the original description by Doesburg (1966), based on a single female (Figs 1-3), *M. fumivenosum* had not been recorded again until now. The citation of this species in the literature is almost non-existent, with the exception of Thompson *et al*. (2017). For example, this species is not listed in the Catalog of the Diptera of Australasia and Oceania (Thompson and Vockeroth 1989).

Herein, newly studied specimens from Papua New Guinea include the first known males of *M. fumivenosum*. We describe the male in full and provide images of the species, including drawings of the male genitalia.

Figs 1-3. *Melanostoma fumivenosum*, holotype female: (1) lateral view; (2) dorsal view; (3) labels.

Materials and methods

The terminology used follows Thompson (1999), except some terms used for the male genitalia that follow the terminology presented by Cumming and Wood (2009).

At the end of each record, between square brackets ([ ]) and separated by a comma, the number of specimens and sex, the holding institution and the unique identifier or number are given. The abbreviations used for collections are: RBINS – Royal Belgian Institute of Natural Sciences, Brussels, Belgium; MZH – Finnish Museum of Natural History, Helsinki, Finland; and ZFMK – Zoologisches Forschungsmuseum Alexander Koenig, Bonn, Germany.

Measurements in millimetres were taken using a reticule in a Leica® M165 C microscope. Photographs were composed using the software Zerene Stacker® 1.04 (Richland, Washington, USA), based on images of pinned specimens taken with a Canon EOS 7D® mounted on a P–51 Cam-Lift (Dun Inc., VA, USA) and with the help of Adobe Lightroom® (version 5.6). Simple-Mappr (Shorthouse 2010) was used to create Fig. 14. Body length was measured from the anterior oral margin to the posterior end of the abdomen, in lateral view. Wing length was measured from the wing tip to the basicosta.

Results

Melanostoma fumivenosum Doesburg, 1966

(Figs 1-12)

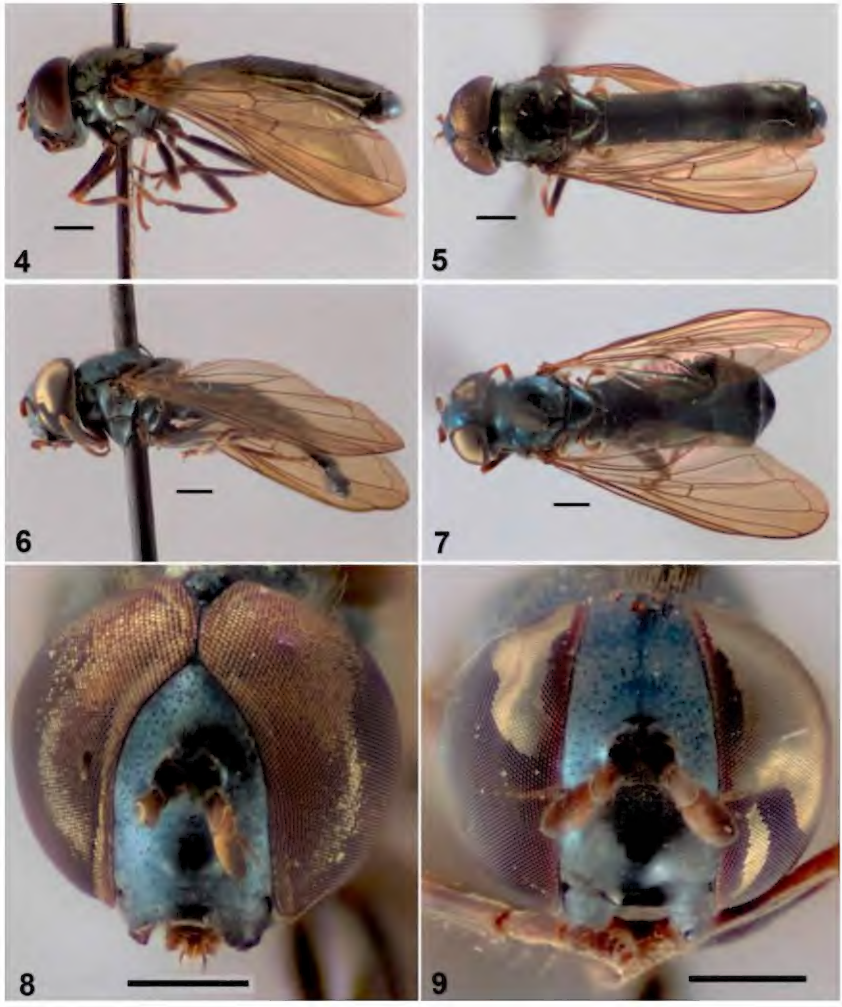
Type locality. Indonesia: Papua Province, Bivak (as Bivach), 05°01'S, 138°39'E (Jong 2000). Knight (2010) also placed this locality in Papua Province.

Material examined. PAPUA NEW GUINEA: 2 ♀♀, Morobe District, Wau, 6-14.iii.1974, H. Hippa & P.T. Lehtinen (MZH, *http://id.luomus.fi/GJ.527*; ZFMK, *http://id.luomus.fi/GJ.526*); 7 ♂♂, Morobe District, Mt. Kaindi, 1800 m, 7-13.iii.1974, H. Hippa & P.T. Lehtinen (MZH, *http://id.luomus.fi/GJ.532*, *http://id.luomus.fi/GJ.534*, *http://id.luomus.fi/GJ.535*, *http://id.luomus.fi/GJ.536*; ZFMK, *http://id.luomus.fi/GJ.530*, *http://id.luomus.fi/GJ.531*, *http://id.luomus.fi/ GJ.533*); 1 ♂, 1 ♀, Morobe District, Mt. Kaindi, 2350 m, 7-13.iii.1974, H. Hippa & P.T. Lehtinen (MZH, *http://id.luomus.fi/GJ.528*, *http://id.luomus.fi/GJ.529*).

In addition, specimens of *M. apicale* from Papua New Guinea were also examined: PNG: Namig Creek, 1105 m., 25.v.1982, P. Grootaert (1♂, RBINS); PNG: Morobe District, Wau, 6-14.iii.1974, H. Hippa & P.T. Lehtinen (4 ♂♂, 7 ♀♀, MZH, *http://id.luomus.fi/GJ.541*, *http://id.luomus.fi/GJ.545*, *http://id.luomus.fi/GJ.554*, *http://id.luomus.fi/GJ.538*, *http://id.luomus.fi/GJ.539*, *http://id.luomus.fi/GJ.540*, *http://id.luomus.fi/GJ.543*, *http://id.luomus.fi/GJ.544*, *http://id.luomus.fi/GJ.553*; ZFMK, *http://id.luomus.fi/GJ.542*, *http://id.luomus.fi/GJ.546*).

Differential diagnosis. *Melanostoma fumivenosum* has an obvious facial tubercle (Figs 4, 6, 8-9) and male genitalia small (Figs 10-12). It is easily distinguishable from *M. fasciatum* by the entirely black abdominal terga (Figs 5, 7), often amply covered with dark pollinosity (*M. fasciatum* has three pairs of large yellow maculae on terga 2, 3 and 4). Moreover, *M. fasciatum* is

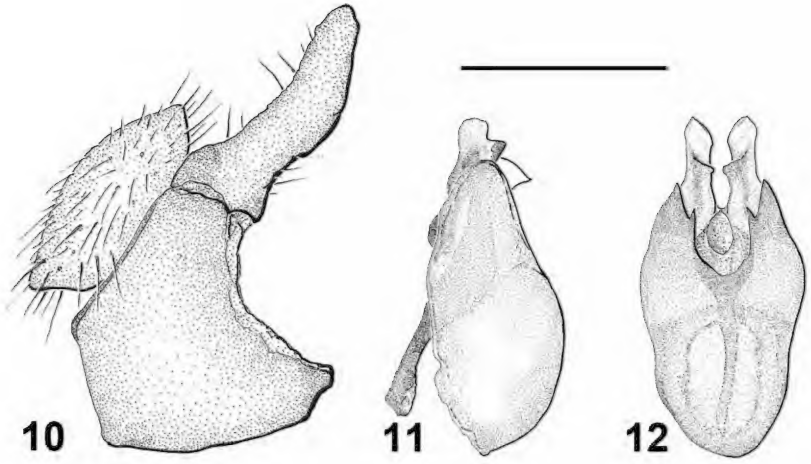
found in New Zealand and *M. fumivenosum* on the island of New Guinea. Other species, such as *M. univittatum*, *M. apicale* and *M. polynesiotes*, have face almost straight, with only a trace of facial tubercle, and enlarged male genitalia.



Figs 4-9. *Melanostoma fumivenosum*: (4-5) male, *http://id.luomus.fi/GJ.533*: (4) lateral view; (5) dorsal view; (6-7) female, *http://id.luomus.fi/GJ.526*: (6) lateral view; (7) dorsal view; (8-9) head showing face: (8) male, *http://id.luomus.fi/GJ.533*; (9) female, *http://id.luomus.fi/GJ.526*. Scale = 1 mm.

Description. *Male*. Head (Figs 4-5, 8): face black with a distinct facial tubercle, dark pilose, grey pollinose except shiny facial tubercle; gena black, dull, dark pilose; lunule black; frons black, dark pilose, grey pollinose laterally and dorsally with a medial shiny area; vertical triangle black, black pilose; eyes holoptic; scape and pedicel dark brown, black pilose, basoflagellomere dark brown except dark orange basoventrally; arista dark brown, pubescent with pile shorter than arista width; occiput black, grey pollinose, pale pilose on ventral 1/2 and dark pilose on dorsal 1/2.

Thorax (Figs 4-5): scutum black, shiny, with sparse grey pollinosity anteriorly and laterally, with erect, relatively long yellow pile; postalar callus brown; scutellum black with long, erect yellow pile, subscutellar fringe with yellow pile. Pleuron black, sparse pale pollinose, yellow pilose; metasternum bare, reduced, excavated; calypter yellow; plumula pale; halter yellow; posterior spiracular fringes yellow. Wing: lightly infuscate, stigma dark yellow, entirely microtrichose. Legs: mostly yellow pilose; coxae dark; metatrochanters dark; femora dark brown with apices faded yellow; pro- and mesotibia dark with basal 1/4 yellow and also yellow apically; metatibia dark brown with basal 1/5 yellow; tarsomeres dark brown.



Figs 10-12. *Melanostoma fumivenosum*, male genitalia, *http://id.luomus.fi/GJ.533*: (10) epandrium, lateral view; (11) hypandrium, lateral view; (12) hypandrium, ventral view. Scale = 0.5 mm.

Abdomen: parallel-sided, unmargined, entirely dark. Tergum 1 black, golden pollinose, yellow pilose. Terga 2–5 black with some purple iridescence laterally, medially entirely black pollinose, with short dark pile medially and longer yellow pile laterally; sterna dark with sparse, pale pile.

Male genitalia: small (Figs 10-12); surstylus elongate, tapering slightly at apex, mildly curved towards dorsal part; postgonites (superior lobes) elongate with slightly pointed apex, with a spur-like process medially in the ventral margin and another spur-like process dorsally pointed anteriorly; hypandrium with two arms each ending with two spur-like processes (one interior, small, and one exterior, larger); phallus unsegmented (Figs 11-12).

Female (Figs 6-7, 9). Similar to male except for normal sexual dimorphism and as follows: frons black, shiny with a broad fascia of pale pollinosity on ventral 1/2 (between antennae insertion and anterior ocellus); abdomen less parallel-sided, broadening from tergum 1 to posterior of tergum 3, sparsely pollinose medially. Eyes dichoptic.

Length (N = 4). Body, 7.5 mm; wing, 6.5 mm.

Geographical distribution. The species is known only from the island of New Guinea (Fig. 13).

Fig. 13. Map of New Guinea showing known distribution of *Melanostoma fumivenosum*. Black triangle: type locality; black circle: new material reported here.

Discussion

Eleven specimens of *M. fumivenosum* were collected in Papua New Guinea during 1974 by Heikki Hippa and Pekka T. Lehtinen. The specimens were found among unidentified material from New Guinea in the Finnish Museum of Natural History, Helsinki, Finland. Among them, we found the first male specimens of this species, endemic to the island of New Guinea, which are described here in full. This species is quite distinct from other *Melanostoma* species of the Australasian and Oceanic Regions in the distinct facial tubercle, overall dark coloration and small male genitalia.

Acknowledgements

We thank Gunilla Ståhls (MZH) and Wouter Dekoninck (RBINS) for letting us study the material in their care. We also thank Yngve Brodin (Swedish Museum of Natural History, Stockholm, Sweden) for permission to use the photographs of the holotype female.

This study has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement no. 642241.

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A NEW SPECIES OF *YOYETTA* (HEMIPTERA: CICADIDAE: CICADETTINI) FROM NEW SOUTH WALES

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Abstract

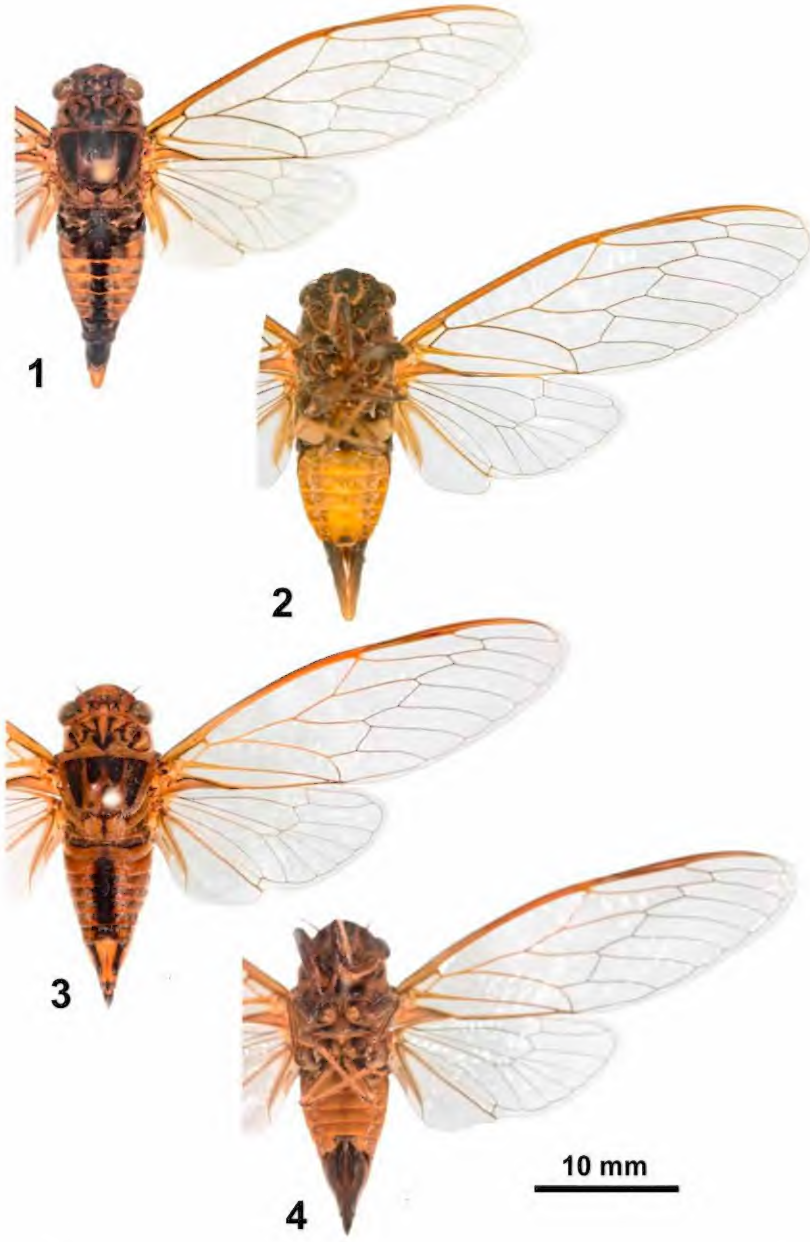
Yoyetta humphreyae **sp. n.** is described from central eastern New South Wales where it is found throughout much of Greater Sydney, the Blue Mountains, immediately inland of the Blue Mountains to Clandulla, and coastal districts north of Sydney north to Taree. The song is analysed and is unusual in that it is perhaps the most structurally diverse of any species in the genus.

Introduction

The genus *Yoyetta* Moulds was established to accommodate a group of cicadas, the males of which have distinctive genitalia (Moulds 2012). The aedeagus is long and thin, turned through 180° in a broad arc distally and which markedly protrudes from the pygofer (Figs 7-10). The genus was fully defined by Moulds (2012) and Emery *et al*. (2015). A key to the 12 described species was provided by Emery *et al*. (2015). In this paper we describe another species, *Yoyetta humphreyae* **sp. n.**, found through much of Greater Sydney, the Blue Mountains and the mid North Coast of New South Wales.

Songs analyses for six described species have been published (Ewart and Popple 2001, Emery *et al*. 2015) and the songs of other undescribed species are currently being studied (L. Popple and D. Emery pers comms). The males of most *Yoyetta* species sing while perched but *Y. aaede* (Walker), *Y. denisoni* (Distant), *Y nigrimontana* Emery, Emery and Popple and *Y. tristrigata* (Goding and Froggatt) sing primarily in flight (Emery *et al*. 2015). *Yoyetta humphreyae* **sp. n.** is another that sings while flying in a ticking manner. Such behaviour is known also in other genera, *e.g*. *Birrima* Distant, *Physeema* Moulds and *Gelidea* Moulds. However, within the same individual cicada, the song of *Y. humphreyae* **sp. n.** is remarkably varied in its several components, possibly the most varied in the genus, so much so that the components could be mistaken for those of different species. Below we give a detailed analysis of this unusual song.

Morphological terminology used in the description of this new species follows that of Moulds (2005, 2012) for body and wing structures, Moulds (2005) for genitalia and Bennet-Clark (1997) for timbals. Abbreviations for collections housing specimens examined are: AMS – Australian Museum, Sydney; AE – Tony Ewart; DE – David Emery; JO – John Olive; LWP – Lindsay Popple; MSM – Max Moulds; QM – Queensland Museum, Brisbane; SAM – South Australian Museum, Adelaide.



Figs 1-4. *Yoyetta humphreyae* **sp. n.**, adult: (1) male, dorsal view; (2) male, ventral view; (3) female, dorsal view; (4) female, ventral view.

Genus *Yoyetta* Moulds, 2012

Yoyetta humphreyae sp. n.

(Figs 1-13)

Cicadetta sp. nr *tristrigata* 486; Emery *et al*., 2005: 103, 109, Fig. 4, Tables 1-3.

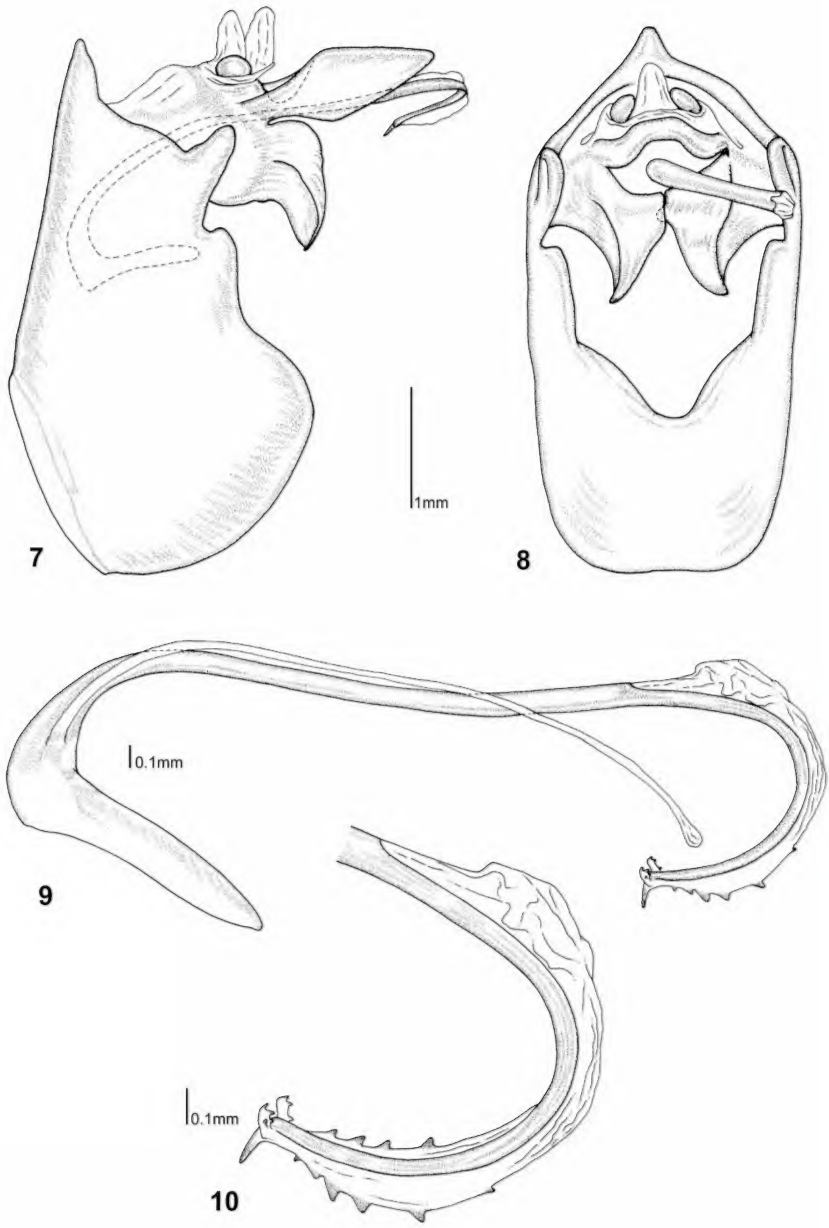
Type material. Holotype ♂, NEW SOUTH WALES: 24 Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey, reg. no. K.463256 (**AMS**).

Paratypes: NEW SOUTH WALES: 2 ♂♂, 24 Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey; 1 ♀, Forestville, Sydney, 30 Dec. 1971, M.S. Moulds (**all AE**). 1 ♂ reg. no. K.463257, 1 ♀ reg. no. 463258, 24 Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey (**AMS**). 1 ♂, 24 Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey; 1 ♀, Lindfield, 28.xii.1982, M. Stevens (**both ANIC**); 1 ♂, Theresa Park, Camden, NSW, 12.xi.1973, D. Emery; 1 ♂, Ingleside, NSW, 20.xi.1994, D. Emery; 3 ♂♂, The Basin, Kuringai-Chase NPk, NSW, 10.xii.1996, T. & D. Emery; 1 ♂, Kinka Reserve, Terrey Hills, NSW, 6.i.1997, D. Emery [genitalia prep]; 1 ♂, same location, 14.xii.1997, D. Emery; 2 ♂♂, same location, 29.xii.1997, S. Emery; 4 ♂♂, same location, 1.i.1998, S., N. & D. Emery; 1 ♂, same location, 20.i.1998, D. Emery; 1 ♀, same location, 29.xi.1998, D. Emery; 1 ♂, same location, 4.xii.1998, N. Emery; 1 ♂, 1 ♀ (*in copulo*), 1 ♀, same location, 4.i.1999, D. Emery; 1 ♂, same location, 8.i.2002, S. Emery; 1 ♀, same location, 2.i.2007, C. & D. Emery; 1 ♀, Booralie Rd, Kuringai Chase NPk, NSW, 6.i.2004, S., N. & D. Emery; 3 ♂♂, Forresters Beach, NSW, 33°24'42"S 151°27'40"E, 15.xi.2009, N. & D. Emery; 2 ♂♂, Archbold Reserve, Forresters Beach, NSW, 12.xii.1998, T. & D. Emery; 1 ♂, Carysfield Park, Bass Hill, NSW, 9.xii.1999, N. Emery; 1 ♂, same location, 4.xii.2000, N. Emery; 1 ♂, same location, 9.xii.2000, S. Emery; 2 ♂♂, same location, 8.xi.2003, S., N. & D. Emery; 1 ♂, same location, 28.xi.2016, D. Emery & L. Popple [DNA]; 1 ♂, Glenbrook, NSW, 19.xi.1998, D. Emery, M. Moulds & B. Day; 1 ♂, Wamberal Cemetery, NSW, 22.xi.2002, D. Emery & L. Popple; 1 ♂, Burragorang Nature Reserve, NSW, 25.xi.2002, D. Emery; 2 ♂♂, Nattai, NSW, 6-14.xi.2003, D. Emery; 1 ♂, 1 ♀, Hat Hill Rd., Blackheath, NSW, 950m, 6.xii.2001, D. Emery; 1 ♂, 1 ♀, same location, 14.xii.2002; 1 ♂, same location, 22.xii.2002, S., N. & D. Emery; 9 ♂♂, 1 ♀, Pulpit Rock Rd jnctn Hat Hill Rd., Blackheath, NSW, 950 m, 33°36'44"S 150°19'28"E, 22.xii.1998, D. Emery; 1 ♀, same location, 9.i.1999, D. Emery; 9 ♂♂, 3 ♀♀, same location, 9.xii.1999, D. Emery; 8 ♂♂, 3 ♀♀, same location, 21-22.xii.2000, S., N. & D. Emery; 14 ♂♂, 5 ♀♀, same location, 9.xii.2009, N. & D. Emery; 2 ♂♂, 1 ♀, same location, 6.xii.2012, N. & D. Emery; 4 ♂♂, 2 ♀♀, Anvil Rock, Blackheath, NSW, 1050 m, 33°35'44"S 150°50'19"E, 17.xii.2016, D. Emery [DNA]; 3 ♂♂, Lockleys Pylon track, Leura, NSW, 33°38'14"S 150°22'02"E, 20.xii.2010, N. & D. Emery; 2 ♂♂, same location, 2.xii.2014, T., S., N. & D. Emery; 2 ♂♂, 1 ♀, same location, 19.xii.2012, N. & D. Emery; 2 ♂♂, Berowra, NSW, 33°37'19"S 150°02'00"E, 18.i.2013, S. Emery & T. Corbin (at light); 1 ♀, Nelson Bay Rd, Anna Bay, NSW, 10.xii.2010, N. & D. Emery; 1 ♂, 1 ♀, Taree, 31°55'36"S 152°27'51"E, 3.i.2013, N., C. & D. Emery; 1 ♂, 1 ♀, Boodi NPk, 33°30'55"S 151°23'22"E, 5.1.2014, N. Emery; 1 ♀, Boomerang Beach, NSW, 30°20'07"S 152°32'23"E, 10.i.2011, D. Hartmann; 5 ♂♂, 1 ♀, Crackneck Point, NSW, 33°23'38"S 151°28'58"E, N. & D. Emery; 1 ♂, St Ives Showground, NSW, 33°42'21"S 151°11'21"E, 6.i.2010, D. Emery; 2 ♂♂, same location, 4.i.2012, N. & D. Emery; 1 ♂, same location, 14.i.2016, D. Emery [DNA] (**all DE**). 1 ♂, 1 ♀, 24

Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey; 4 ♂♂, 1 ♀, Wamberal Cemetery, 22.xi.2002, L. Popple, D. Emery. 486-0001 (recorded LWP) to 486-0005, (1 ♂ genitalia prep. 486-01); 2 ♂♂, Clandulla district, 32°52'51"S 149°56'27"E, 8.i.2010, Popple & Emery, open woodland (**all LWP**). 1 ♂ (genitalia prep. Y0 46), Cooranbong, 7 Dec. 1997, C. Holmes; 1 ♂ (genitalia prep. Y0 52), Mt Colah railway station, 10 Oct. 2010, H.M. Smith; 1 ♂, Asquith, Sydney, Dec. 2006, Moulds & Humphrey; 26 ♂♂ (4 genitalia preps Y0 50, 55, 57, 58), 4 ♀♀, 24 Orana Ave, Hornsby, Sydney, 25 Dec. 1997, 1, 2-4, 5-20 Jan. 2000, M. Humphrey; 10 ♂♂ (2 genitalia preps Y0 47, 54), 7 ♀♀, Forestville, Sydney, 30 Dec. 1971, M.S. Moulds; 1 ♂, same locality, 26 Nov. 1975, M.S. & B.J. Moulds; 1 ♂ (genitalia prep. Y0 59), Blackheath, Blue Mts, 1 Apr. 1987, F.G. Sattler (**all MSM**). 2 ♂♂, 24 Orana Ave, Hornsby, Sydney, 5-20 Jan. 2000, M. Humphrey (**JO**). 1 ♂, 24 Orana Ave, Hornsby, Sydney, 2-4 Jan. 2000, M. Humphrey; 1 ♂, 1 ♀, Forestville, Sydney, 30 Dec. 1971, M.S. Moulds (**all QM**). 1 ♂, Galston, Dumbrell; 1 ♂, *Melampsalta landsboroughi*, Sydney, H. Ashton, 5.7.[19]06, SAMA Database No. 20-14628; 1 ♂, Sydney, SAMA Database No. 20-014625; 1 ♀, Sydney, Lea, *M. landsboroughi* Dist. N.S.W. Q.S.A., Determined H. Ashton, SAMA Database No. 20-14626 (**all SAM**).

Description. Male (Figs 1-2, 5-10). *Head* about as wide as lateral margins of pronotum; mostly black with a dull orange triangular spot between lateral ocelli based on posterior margin; supra-antennal plates black, occasionally edged yellow; ocelli light brown; postclypeus black with inner dorsal surface dull orange, a narrow dull yellow lateral margin and sometimes a partly dull orange midline; anteclypeus shiny black; rostrum reaching bases of hind coxae, mostly brown basally becoming black apically; antennae black.

Figs 5-6. *Yoyetta humphreyae* **sp. n.**, male: (5) left timbal with ribs numbered and vestigial timbal cover arrowed; (6) right operculum.



Figs 7-10. *Yoyetta humphreyae* **sp. n.**, male genitalia: (7) lateral view; (8) ventral view); (9) aedeagus, lateral view; (10) distal aedeagus showing detailed morphology.

Thorax mostly black. Pronotum with a broad black fascia along midline usually partly dull orange centrally, otherwise extensively blotched dull orange; pronotal collar a suffused mixture of black and dull orange. Mesonotum black sometimes with hints of brown following parapsidal sutures; cruciform elevation dull orange apart from a broad black midline and black anterior arms; wing grooves mainly dull orange suffused with some black. Metanotum mainly dull orange suffused black but shiny black near hind wing bases. Thorax below black often suffused brown and usually with edges of mid and hind leg cavities reddish brown.

Legs black with dull orange markings variable between individuals. Fore coxae about half black, half dull orange; mid and hind coxae tending dull orange distally; fore femora with inner surface usually black but sometimes mainly dull orange, the outer surface predominantly dull orange to varying degrees but usually black along femoral spines; mid and hind femora light brown to almost black but usually tending dull orange at distal joint; tarsi dull yellow suffused black; meracantha black on about basal half, otherwise dull white or occasionally pale brown.

Wings with forewing costal margin orange-brown to almost black, otherwise venation mainly black but usually light brown at base to vein CuP+1A; basal membrane light brown orange. Hindwing venation black; plaga light brown.

Opercula black basally, otherwise very pale brown (Fig. 6).

Timbals (Fig. 5) with five long ribs; ribs 1-4 spanning the timbal membrane, fused dorsally on basal spur; rib 5 short, detached from others, occupying dorsal half of timbal only; timbal plate with well developed, elongate dome bearing a distinct point of apodeme attachment near centre (blurred in Fig. 5).

Abdomen with tergites 1 and 2 black; tergite 2 with a low anterior, backwardly-curved ridge homologous with a timbal cover (Fig. 5), tergites 3-7 predominantly orange each with a large black mark on dorsal midline all gradually increasing in size towards anterior but that on tergite 3 much larger; tergites 3-7 also black sublaterally against posterior margin considerably variable in extent between individuals; tergite 8 black except for orange mark at lower anterior corner. Sternite I mainly orange; sternite II black except for partly orange posterior margin; sternites III–VII orange except for small black spot on VII at centre of posterior margin; sternite VIII black becoming orange-brown apically.

Genitalia (Figs 7-10) with pygofer upper lobe of moderate size, gradually tapering to a broadly rounded apex; basal pygofer lobe small weakly developed, broadly rounded; median lobe of uncus very large, very long, concave ventrally, in lateral view narrow basally, expanded around mid length to widest width, thereafter evenly tapering to a bluntly pointed apex; claspers robust, claw-like, partially meeting, in ventral view their inner margins diverging and their outer margins gently turned outwards; aedeagus

recurved distally through 180 degrees, the vesica weakly toothed either side subapically, apex terminating in a short, slender 'beak' pointing outwards and a pair of very small flat ear-like lobes pointing inwards minutely toothed; pseudoparameres very long, nearly reaching most distal part of theca, very slender, hair-like and weakly knobbed apically.

Female (Figs 2-3). Similar to male but differing as follows. Thorax usually more distinctly marked and never nearly all black as in some males. Abdomen mainly brown to orange. Tergite 1 mainly black; tergites 3-8 with an uninterrupted, broad, black, dorsal midline, the black often protruding laterally to varying degrees on anterior half of sternites 4-8; and tergites 3-8 each with a sublateral black spot. Sternite II mainly black; sternites III-VIII orange; sternite VIII black around midline. Abdominal segment 9 brown with a pair of sharply defined, paramedian black bands on anterior three-quarters; and a small black lateral spot below distal end of each black band. Ovipositor sheath black, extending less than 1 mm beyond apex of abdomen.

Measurements (in mm; range with mean in parentheses for 10 males and 10 females, including smallest and largest specimens). *Length of body including head*: male 21.1-25.0 (23.2); female 21.1-24.2 (22.4). *Length of forewing*: male 25.9-28.2 (27.2); female 28.8-31.2 (29.9). *Width of forewing*: male 8.7-9.7 (9.2); female 9.9-11.0 (10.2). *Ratio width/length of forewing*: male 2.8-3.2 (3.0); female 2.8-3.1 (2.9). *Width of head (including eyes)*: male 6.0-6.5 (6.3); female 6.6-7.4 (7.0). *Width of pronotum (across lateral angles)*: male 6.5-7.3 (7.0); female 6.8-7.9 (7.4).

Distinguishing features. Most similar to *Y. repetens* Emery, Emery & Popple, *Y. cumberlandi* Emery, Emery & Popple, *Y. tristrigata* (Goding & Froggatt) and some undescribed species allied to *Y. tristrigata*. Males differ in the larger black dorsal mark on tergite 3 that extends laterally well past the upper level of the timbal cavity. They differ significantly from all other known *Yoyetta* species in their genitalia, which have an exceptionally long uncus, about as long as the distance between the apices of the upper pygofer lobe and dorsal beak. Females are indistinguishable from those of *Y. tristrigata*, although *Y. tristrigata* is separated geographically, being restricted to tropical northeastern Australia. They can be separated from all other *Yoyetta* species by having in combination, a hind wing plaga brownish rather than white, a predominantly brown thorax and abdomen, an ovipositor that protrudes less than 1 mm, a forewing longer than 24 mm, a pale cruciform elevation.

Etymology. Named for Dr Margaret Humphrey in recognition of her contribution to Australian entomology and arachnology as lecturer, museum curator and researcher, and who collected several specimens of this new species.

Distribution and habitat (Fig. 11). Throughout much of Greater Sydney south-west to Nattai , the Blue Mountains and immediately inland of the Blue

Mountains to Clandulla, and coastal districts north of Sydney north to Taree on the mid North Coast of New South Wales.

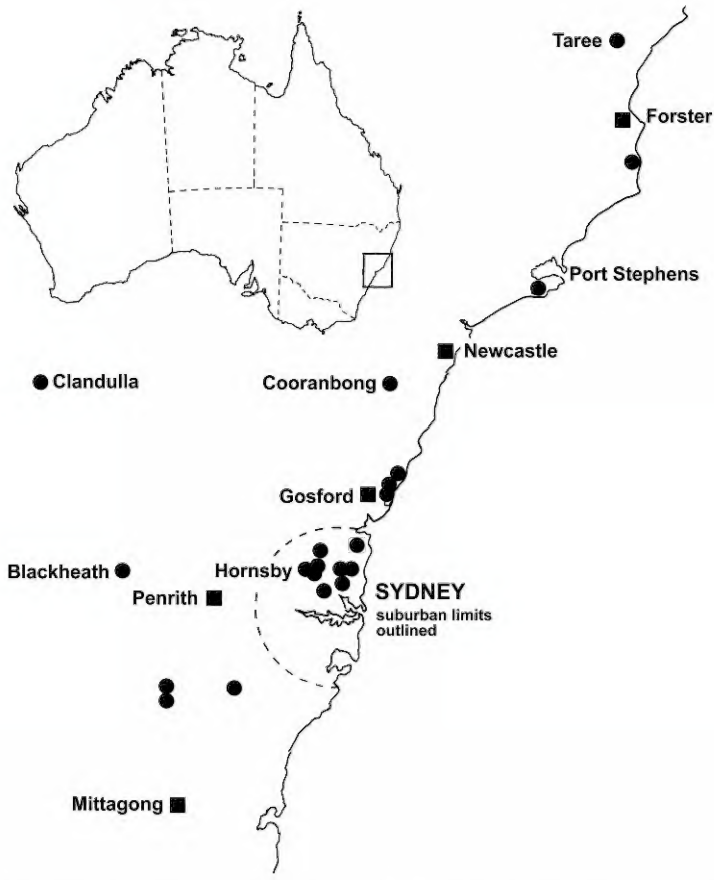


Fig. 11. Distribution of *Yoyetta humphreyae* **sp. n.** Collection localities are shown as black circles. Towns without collection records are shown as black squares. Approximate boundary of metropolitan Sydney is marked by a dashed semi-circle.

Calling song. The call of *Yoyetta humphreyae* (Figs 12-14) is perhaps the most varied of any species in the genus. Indeed, it is so structurally diverse that it might take an observer some time to realise that the various components are all produced by the same individual males of the same species. Despite the variation within individuals, the song appears to be quite consistent across the small geographical distribution of this species (Fig. 11). The following detailed description is compiled following the examination of four recordings, all made by LWP.

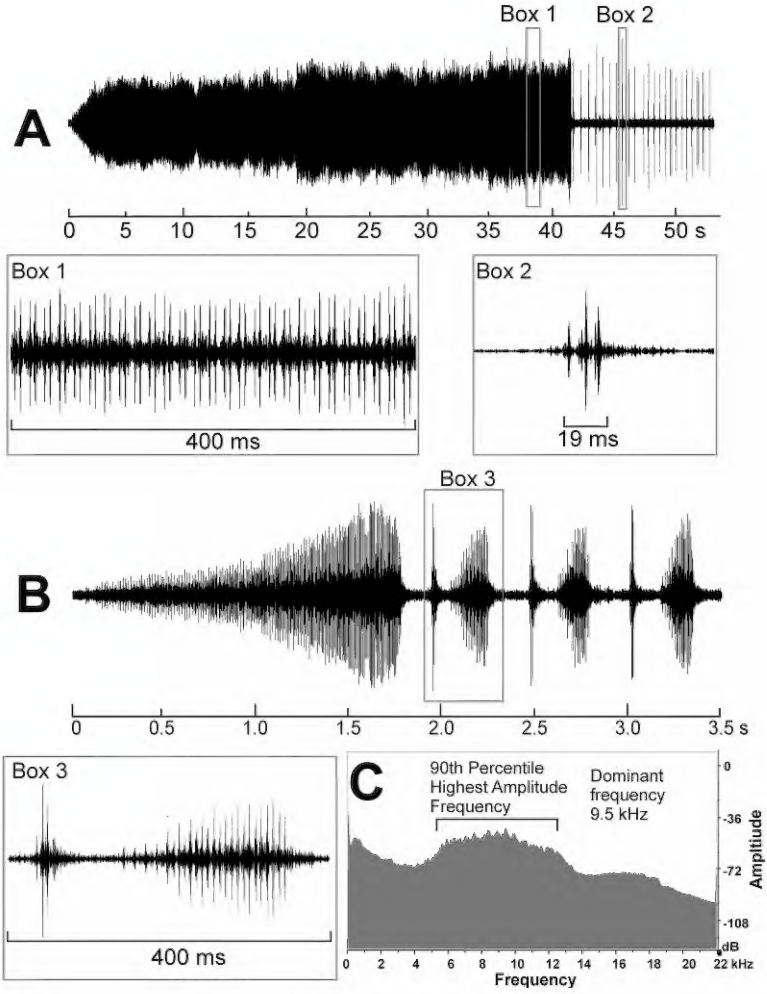


Fig. 12. *Yoyetta humphreyae* **sp. n.**, male calling song structure. (A) illustrates a complete sequence from the first part of the calling song, comprising a single extended echeme followed by a series of sharp clicks. Box 1 and Box 2 are expanded from (A) to illustrate the detailed structure of the extended echeme and a single sharp click, respectively. (B) illustrates a single sequence from the second part of the calling song, including a long echeme followed by a series of three repeated phrases. Each phrase is composed of a single sharp click followed by a short echeme. Box 3 is expanded from (B) to illustrate the detailed structure of a single phrase. (C) is a spectrogram illustrating song frequency. The specimen was recorded in the field at Wamberal Cemetery (33°25'S 151°27'E) by LWP using a Sony MZR700 minidisc recorder with Sony ECM-MS957 Electret Condenser microphone (linear frequency response up to 18 kHz).

The calling song comprises three separate parts. These can interchange freely during song production. The first part commences with a single extended echeme (30-60 s duration), which is quiet at the beginning and gradually increases in amplitude as it progresses. The echeme then ends abruptly and is followed by a series of 10-30 sharp clicks, each 0.008-0.014 s and each separated by gaps of 0.2-0.6 s. The structure of this part is illustrated in Figure 12A (with the detailed structure of the echeme expanded in Box 1 and a single click shown in Box 2 of this figure). Males produce this part when they are settled and stationary, often after a long bout of silence. Observations by LWP indicate that it is usually produced once (*i.e.* without multiples successive repeats) before moving on directly to the second part or third part.

The second part of the calling song consists of simple, repetitive sharp clicks (each 0.04-0.14 s and each separated by gaps of 0.18-0.65 s). These are closely similar to the clicking structures at the end of the first part (as illustrated in the final 14 seconds of the wave plot in Figure 12A), the principal difference being that these clicks are produced predominantly in flight. An example is provided in Figure 13A (with click structures expanded in Box 1 of this figure). When producing this second part, the male weaves past trees and shrubs from canopy height to near ground level. In comparison with the first part, this second part proves challenging for acoustic recording, due to the males being highly mobile. However, it is often the dominant part of the calling song and almost certainly the most conspicuous in a natural setting.

The third part is illustrated in Figures 12B and 14. It commences with a long echeme that is shorter than the extended echeme characteristic of the beginning of the first part, being only 0.4-0.9 s duration. The echeme shows a marked increase in amplitude as it progresses and is followed by a gap (0.05-0.25 s duration). This is then followed by a series of three (rarely four) defined phrases. Each phrase comprises a sharp click (0.008-0.014 s duration), a short gap (0.04-0.14 s duration), a short echeme (~0.1-0.15 s duration) and a longer gap (0.07-0.18 s duration). The complete sequence, with a long echeme followed by repeated phrases is shown in Figure 12B (with a detailed structure of a single phrase provided in Box 3 of this figure). Comparative recordings of the same sequence recorded at multiple localities are illustrated in Figure 14. The sequence might be repeated multiple times, although gaps between repeats can last several seconds. These periods of silence are often interrupted by one or two short echemes (0.2-0.3 s duration). Males remain stationary during each sequence, although they sometimes fly short distances between repeats. They might also engage in brief bouts of clicking (as per the second part described above) when flying. Observations by LWP indicate that females respond with a timed wing-flick in the long gaps at the end of each repeated phrase. After some time when no response is received, males switch to the first or second part of the calling song.

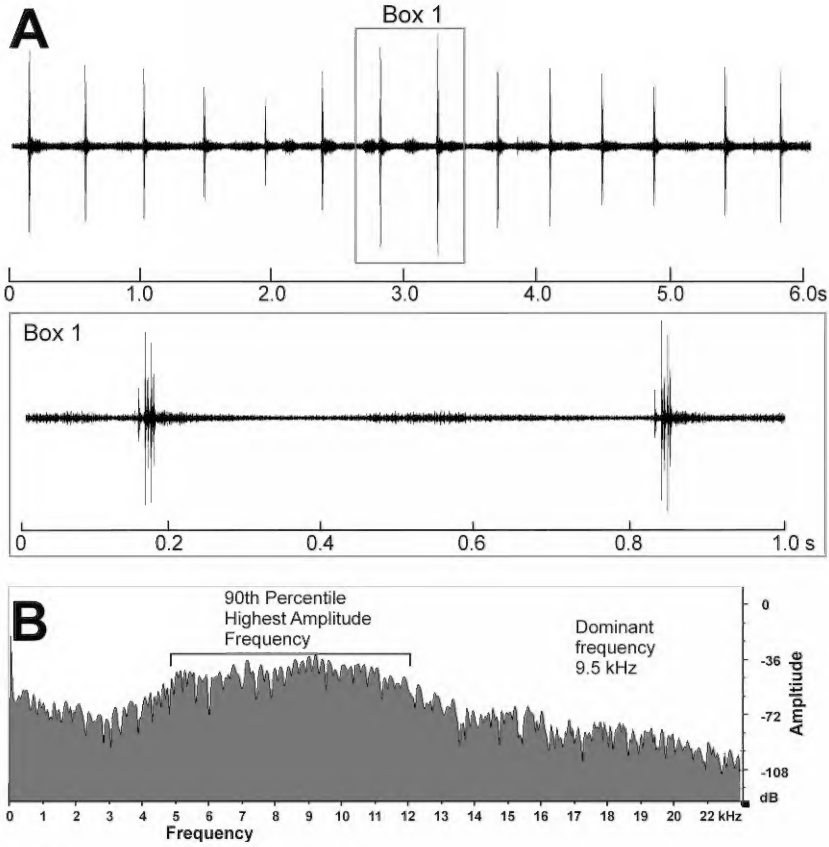


Fig. 13. *Yoyetta humphreyae* **sp. n.**, male calling song structure. (A) illustrates a typical sequence from the second part of the calling song, comprising a series of sharp clicks, produced in flight. Box 1 is expanded from (A) to illustrate the detailed structure of two sharp clicks. (B) is a spectrogram illustrating song frequency. The specimen was recorded in the field at Nattai (34°04'S 150°26'E) by LWP using the equipment detailed in the caption for Fig. 12.

The calling song has a highest amplitude frequency plateau between 5.6 and 12.3 kHz, with a dominant frequency of approximately 9.5 kHz (Figs 12C, 13B). This frequency distribution remains constant across all three parts of the song.

Phylogenetic relationships

Emery *et al.* (2015) recognised three informal groupings within *Yoyetta*, the *abdominalis group* with hind wing plaga almost entirely opaque and mainly white and abdominal tergites 2-7 mainly black or dark brown; the *incepta group* with hind wing plaga opaque and cream to pale orange-brown along

the majority of the jugal fold and part of outer margin, and abdominal tergites mainly black; and the *tristrigata group* with hind wing plaga opaque and cream to light brown or orange-brown along majority of jugal fold and 50-100% of outer margin, and abdominal tergites 2-7 mainly orange to yellow-brown. *Yoyetta humphreyae* falls within the *tristrigata* group. However, it appears to show no close affiliation with any of the described species, differing noticeably in its exceptionally long uncus (Fig. 7) and in the 'ears' and downturned 'beak' at the apex of the theca (Figs 9-10). A similar thecal apex is found in some as yet undescribed *Yoyetta* species but the long uncus is otherwise unknown in the genus.

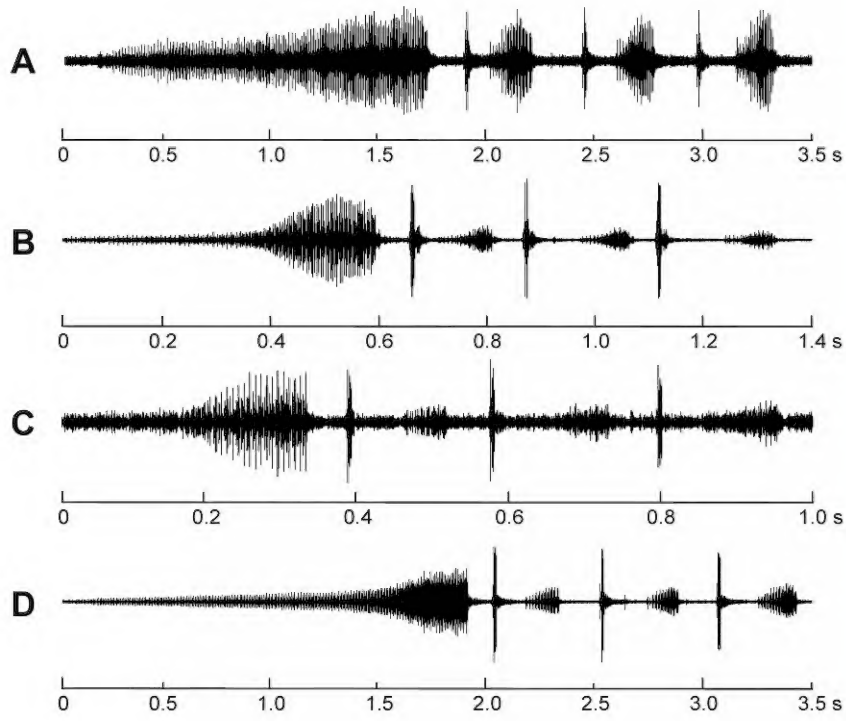


Fig. 14. *Yoyetta humphreyae* **sp. n.**, waveplots comparing the male calling song phrase structure from four different localities: (A) Wamberal Cemetery (33°25'S 151°27'E), (B) Clandulla State Forest (32°53'S 149°56'E), (C) Carysfield Park, Bass Hill (33°54'S 151°00'E), and (D) Nattai (34°04'S 150°26'E). All recordings were made in the field by LWP using the equipment detailed in the caption for Fig. 12 (recordings A, C & D) or with an Audio-Technica ATR-55 cardioid condenser shotgun microphone (linear frequency response up to 18 kHz; recording B).

Acknowledgements

We thank David Emery for helpful discussion and for access to specimens in his collection. Peter Hudson kindly provided access to specimens in the South Australian Museum. For the photographs used in Figs 1-4 we are grateful to Gary Wilson and for Figs 5-6 we thank David Rentz. The drawings in Figs 7-10 were kindly done by Hannah Matthews.

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The dragonfly, *Hemicordulia australiae* (Rambur), in the wheel position near a garden pond at Currimundi, on the Queensland Sunshine Coast. This species is widespread in Australia, the Lesser Sundas and New Zealand. At the stage depicted the male (top) has previously transferred his sperm from the testes at the tip of the abdomen to the seminal vesicle on the second segment near the base of the abdomen. The female has made genital contact forming the heart-shaped 'wheel', during which the male inseminates her. Pen and ink drawing by *Australian Entomologist* subscriber, Dr Albert Orr, whose illustrated books on dragonflies and butterflies have won awards in Australia and overseas.

NOTES FOR AUTHORS

We welcome manuscripts dealing with non-pest aspects of the native insect and arachnid faunas of Australia, New Guinea, New Zealand and islands in the south-western Pacific region. Manuscripts for consideration for publication should be submitted in Microsoft Word. Digital illustrations should be sent initially as low resolution images in a separate Word file, as low resolution JPEGs, or as low resolution PDF files, with figure numbers indicated clearly for each figure. High resolution TIFFs or JPEGs (300 dpi at print size) must be provided at the time of acceptance of the manuscript. Digital manuscripts and illustrations may be sent via email to geoff.monteith@bigpond.com or can be posted on disk or USB to:

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Printed by Bayfield Printing, Unit 6/60 Kremzow Rd, Brendale, Q 4500, Ph: 1300 685 820